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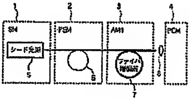
(54)【発明の名称】　モジュール式、高エネルギ、広波長可変性、超高速、ファイバ光源

(57)【要約】　（修正有）
【課題】高ピーク超短パルスを効率よく発生するモジュール式小型広波長可変レーザシステムを提供する。
【解決手段】システムの小型化はダイオードレーザで直接あるいは間接にポンプされた効率のよいファイバ増幅器を採用することで確実に行われる。ファイバ増幅器のピークパワー処理能力は分散的に広がったパルスはもちろん、最適化されたパルス形状を使うことで、高められる。分散広がりは自己位相変調と利得の存在下で分散パルスが拡張することで導入され、高パワー放物線状パルスの形成をもたらす。増幅後、分散的に広がったパルスは、別のセットの分散遅延ラインを実装することで、バンド幅限界近くまで再圧縮される。全体のシステムの広い波長可変性を確実にするために、非線形光学結晶での周波数変換と合同して超短パルスの小型光源のラマンシフトが実施される。さらに、正分散光増幅器、ラマン増幅器ファイバを利用する。



【特許請求の範囲】

【請求項１】０．３ｎｍ以上のスペクトルバンド幅と、約５０ｆｓと１ｎｓの間のパルス幅とをもつ波長範囲１～１．１５μｍのパルスを発生するシード光源と、該パルスを入力して増幅し、増幅したパルスを出力する広いバンド幅のパルスのためのファイバ増幅器と、該ファイバ増幅器にレーザエネルギを供給するためのポンプレーザと、を有するレーザシステム。

【請求項２】前記シード光源は、ファイバレーザと、該ファイバレーザの出力を入力するラマンシフタと、該ラマンシフタの出力を周波数逓倍する非線形結晶と、を有する請求項１に関するレーザシステム。

【請求項３】前記ラマンシフタは、前記ファイバレーザの放射波長を２０００ｎｍより長いスペクトル範囲に上方変換するシリカベースのファイバであり、さらに前記非線形結晶は、その後、該上方変換された波長を１０００～１５００ｎｍのスペクトル範囲に下方変換する、請求項２に関するレーザシステム。

【請求項４】非線形結晶の波長同調曲線は、ラマンシフタの出力の中心波長以下である請求項２に関するレーザシステム。

【請求項５】前記ラマンシフタは、非増幅ファイバ、あるいは屈折率分布と約６００～５０００ｎｍの波長範囲のパルスを発生するために選定された希土類増幅イオンとをもつ増幅ファイバ、を有する請求項２に関するレーザシステム。

【請求項６】前記シード光源は、Ｅｒファイバレーザと、該Ｅｒファイバレーザの出力を入力し、前記ファイバ増幅器に出力するシリカラマンシフトファイバと、前記増幅されたパルスを入力するフッ化ラマンシフタと、を有し、前記ファイバ増幅器は、Ｔｍファイバ増幅器である、請求項１に関するレーザシステム。

【請求項７】周波数逓倍理論を実行するようにフッ化ラマンシフトファイバの出力を入力する非線形結晶をさらに有する請求項６に関するレーザシステム。

【請求項８】前記シード光源は、Ｅｒファイバレーザと、周波数逓倍理論を実行するように該Ｅｒファイバの出力を入力する非線形結晶と、該非線形結晶の周波数逓倍出力を入力するラマンシフタと、を有する請求項１に関するレーザシステム。

【請求項９】前記シード光源は、受動的モードロックファイバレーザであり、前記ラマンシフトファイバは、非線形結晶の周波数逓倍出力を約７５０ｎｍから約１０５０ｎｍの波長範囲にラマンシフトさせるために使用されるホーリファイバである、請求項８に関するレーザシステム。

【請求項１０】前記シード光源は、受動型モードロックファイバレーザであり，一連の非増幅ファイバおよび異なる屈折率分布と異なる希土類増幅イオンをもつ増幅ファイバは、前記非線形結晶の周波数逓倍出力を約７５０

ｎｍから約５０００ｎｍの波長範囲にラマンシフトするために使用される、請求項８に関するレーザシステム。

【請求項１１】前記シード光源は、受動型モードロックファイバレーザを有する、請求項１に関するレーザシステム。

【請求項１２】前記受動型モードロックファイバレーザは、Ｙｂファイバレーザである、請求項１１に関するレーザシステム。

【請求項１３】前記受動型モードロックファイバレーザは、Ｎｄファイバレーザである、請求項１１に関するレーザシステム。

【請求項１４】前記受動型モードロックファイバレーザは、多モードである、請求項１１に関するレーザシステム。

【請求項１５】前記受動型モードロックファイバレーザは、偏光保持である、請求項１４に関するレーザシステム。

【請求項１６】前記受動型モードロックファイバレーザは、単一モードで偏光保持である、請求項１１に関するレーザシステム。

【請求項１７】前記シード光源は、ファイバレーザと、該ファイバレーザの出力を入力し反ストークスブルーシフト出力を出力する周波数シフトファイバと、を有する、請求項１に関するレーザシステム。

【請求項１８】前記ファイバレーザは、Ｅｒ，Ｅｒ／Ｙｂ，あるいはＴｍファイバレーザである、請求項１７に関するレーザシステム。

【請求項１９】前記シード光源は、前記ファイバ増幅器で放物線状パルスの生成を誘起するパルスを発生する、請求項１に関するレーザシステム。

【請求項２０】前記シード光源と前記ファイバ増幅器との間にあって、該シード光源を該ファイバ増幅器に結合し、１Ｋｍ以下の長さの光ファイバをもつ結合器をさらに有する請求項１９に関するレーザシステム。

【請求項２１】前記ファイバ増幅器の出力に結合された光供給ファイバをさらに有する請求項１に関するレーザシステム。

【請求項２２】前記光供給ファイバは、ホーリファイバ、一本の数モードファイバおよび一本あるいは二本の単一モードファイバに接続された一本の数モードファイバからなる群から選択される請求項２１に関するレーザシステム。

【請求項２３】前記シード光源は、前記ファイバ増幅器で放物線状パルスの生成を誘起するように１００ｐｓより短いパルスを発生し、さらに、前記ファイバ増幅器は、１０より大きい利得をもつ、請求項２２に関するレーザシステム。

【請求項２４】前記シード光源からパルスを受けて該パルスをちょうどよいときに分散的に拡張し、該拡張したパルスを前記増幅器に出力するパルス拡張器をさらに有

する請求項２３に関するレーザシステム。

【請求項２５】前記増幅されたパルスを時間的に圧縮するパルス圧縮器を有し、該パルス圧縮器の分散は、該パルス圧縮器がおおよそバンド幅限界パルスを出力するようなものである、請求項２４に関するレーザシステム。

【請求項２６】前記シード光源は、ＴｍあるいはＨｏファイバレーザと、該ＴｍあるいはＨｏファイバレーザの出力を入力し周波数逓倍理論を実行する非線形結晶と、を有する請求項１に関するレーザシステム。

【請求項２７】前記ファイバ増幅器は、ＹｂあるいはＮｄのどちらかが添加される請求項１に関するレーザシステム。

【請求項２８】増幅されたパルスをおおよそバンド幅限界まで時間的に圧縮するためのパルス圧縮器を、さらに有する請求項１に関するレーザシステム。

【請求項２９】前記シード光源は、直接変調された半導体レーザである請求項１に関するレーザシステム。

【請求項３０】０．３ｎｍより大きいスペクトルバンド幅と約５０ｆｓと１ｎｓの間のパルス幅とをもつ１～１．１５μｍの波長範囲のパルスを発生するシード光源と、該パルスを受けて該パルスをちょうどよいときに分散的に拡張し、該拡張したパルスを出力するパルス拡張器と、広いバンド幅のパルスに対して１０より大きな利得をもち、該拡張したパルスを受けて増幅しかつ出力するクラッドポンプファイバ増幅器と、該増幅され拡張されたパルスを入力し、それらをおおよそバンド幅限界まで時間的に圧縮するパルス圧縮器と、を有するレーザシステム。

【請求項３１】前記パルス拡張器は、１ｋｍ以下の長さのファイバを有する請求項３０に関するレーザシステム。

【請求項３２】前記パルス拡張器は、ホーリファイバを有する請求項３０に関するレーザシステム。

【請求項３３】前記パルス拡張器は、一本の少数モードファイバを有する請求項３０に関するレーザシステム。

【請求項３４】前記パルス拡張器は、一本あるいは多数の単一モードファイバと一緒に接合された一本の少数モードファイバを有する請求項３０に関するレーザシステム。

【請求項３５】前記パルス拡張器は、１ｋｍ以下の長さの単一モードファイバを有する請求項３０に関するレーザシステム。

【請求項３６】前記パルス拡張器は、Ｗ状屈折率プロファイルをもつファイバを有する請求項３０に関するレーザシステム。

【請求項３７】前記パルス拡張器は、多クラッド屈折率プロファイルをもつファイバを有する請求項３０に関するレーザシステム。

【請求項３８】前記パルス拡張器は、負の３次分散をもつ一本のファイバと、負の２次分散をもつ線形チャープファイバ回折格子と、を有する請求項３０に関するレーザシステム。

【請求項３９】前記パルス拡張器は、線形チャープファイバ回折格子と、パルス圧縮手段で高次分散を補償するように、３次および高次分散の選択できる値をもつ一つあるいはより多くのファイバ透過型回折格子と、を有する請求項３０に関するレーザシステム。

【請求項４０】前記パルス拡張器と前記パルス圧縮器の間に接続された複数の付加的ファイバ増幅器と、１ｋｍ以下の長さの光ファイバを有し、前記シード光源を該複数の付加的増幅器の最初の一つに結合するファイバ結合器と、該ファイバ増幅器の前、該複数の付加的ファイバ増幅器の後、あるいは該増幅器のどれかの中間、のいずれかに配置された複数のパルス採集手段と、をさらに有する請求項３０に関するレーザシステム。

【請求項４１】　０．３ｎｍより大きいスペクトルバンド幅と約５０ｆｓと１ｎｓの間のパルス幅とをもつ１～１．１５μｍの波長範囲のパルスを発生するシード光源と、少なくとも一つの前方パスと一つの後方パスで動作する増幅器であって、該パルスを受けて増幅し、出力する、広いバンド幅のパルスためのクラッドポンプファイバ増幅器と、該ファイバ増幅器にレーザエネルギを供給するためのポンプレーザと、該増幅器の一つの前方パスと一つの後方パスの間に配置された光変調器と、を有するレーザシステム。

【請求項４２】複数の付加的ファイバ増幅器と、ここで少なくとも一つおよび複数の付加的ファイバ増幅器は、少なくとも一つの前方パスと一つの後方パスで動作する、少なくとも一つの前方パスと一つの後方パスで動作する前記の少なくとも一つのファイバ増幅器と複数の付加的ファイバ増幅器の最初のパスの後に配置された増幅器の基本モードを優先的に透過するモードフィルタと、をさらに有する請求項４１に関するレーザシステム。

【請求項４３】少なくとも一つの前方パスと一つの後方パスの間に配置された一つのパルス採集器を、さらに有する請求項４２に関するレーザシステム。

【請求項４４】２μｍより大きな出力波長で動作するパルス光源であって、短パルス幅のパルスを出力するシード光源と、該パルスを入力し、該出力波長を生成する第一ファイバラマンシフタと、を有するパルス光源。

【請求項４５】前記第一ファイバラマンシフタに接続された少なくとも一つの付加的ファイバラマンシフタと、該ファイバラマンシフタの間にかわるがわる接続された複数のファイバ増幅器と、をさらに有する請求項４４に関するパルス光源。

【請求項４６】前記ファイバラマンシフタの最後の一つに接続された逓倍結晶をさらに有する請求項４５に関するパルス光源であって、該非線形結晶の波長同調曲線が、ラマンシフトされ増幅されたシードパルスのラマンスペクトル成分の中心波長以下に選定されるパルス光

源。

【請求項４７】受動型モードロックファイバレーザと、該ファイバレーザの出力を増幅するためのＹｂ増幅器と、を有する光パルス光源。

【請求項４８】前記受動型モードロックファイバレーザは、Ｙｂファイバレーザを有する請求項４７に関する光パルス光源。

【請求項４９】１０ｄＢ／ｋｍ以下の利得と１０ｄＢ以上の総合利得をもつ光ファイバ透過ラインに接続された純粋正分散ファイバ光増幅器と、該光ファイバ透過ラインに配置された分散補償素子と、該光ファイバ透過ラインに配置された光学フィルタと、を有する光通信サブシステム。

【請求項５０】３ｄＢ／ｋｍ以下の利得と２０ｄＢ以上の総合利得をもつ光ファイバ透過ラインに接続された純粋正分散ファイバ光増幅器と、光ファイバ透過ラインの一端に配置された分散補償素子と、を有する光通信サブシステム。

【請求項５１】光ファイバ透過ラインに接続された正分散光ファイバ素子と、光ファイバ透過ラインにやはり接続された光負分散素子と、を有する光通信サブシステムであって、該光ファイバ透過ラインを透過する光パルスで受けた自己位相変調の量は、光負分散素子でよりも正分散光ファイバ素子での方が多い、光通信サブシステム。

【請求項５２】前記負分散素子は、チャープファイバ回折格子を有する請求項５１に列挙された光通信サブシステム。

【請求項５３】光ファイバ透過ラインに接続された純粋正分散をもつ複数のホーリファイバと、光ファイバ透過ラインにやはり接続された複数の光負分散素子と、を有する光通信サブシステムであって、光ファイバ透過ラインを透過する光パルスで受けた自己位相変調の量は、光負分散素子でよりもホーリファイバでの方が多い、光通信サブシステム。

【請求項５４】１０ｎｓ以下の長さをもつポンプパルス列を入力し、光信号も入力し、増幅し、出力する光ラマン増幅器ファイバを有する光通信サブシステムであって、該光信号は、該ラマン増幅器ファイバをポンプパルスに関して反対方向に伝搬する、光通信サブシステム。

【請求項５５】前記光ラマン増幅器は、前記ポンプパルスに実施される同調操作で同調される、請求項５４に関する光通信サブシステム。

【請求項５６】光パルスを出力するシード光源と、該光パルスを変調する変調器と、該変調された光パルスを入力するラマンシフタファイバと、該ラマンシフタファイバの出力を入力するラマン増幅器と、を有する請求項５５に関する光通信サブシステム。

【請求項５７】前記同調操作は、前記シードパルスが前記ラマンシフタファイバに注入されるまえに、該シードパルスのパワー、波長および幅の少なくとも一つを変調することを含む、請求項５６に関する光通信サブシステム。

【請求項５８】前記ラマンシフトファイバは、分散がある意味で前記ラマンシフトを最適化するように波長で変化するホーリファイバである、請求項９に関するレーザシステム。

【請求項５９】シードパルスの光源と、該シードパルスを入力し増幅するファイバ増幅器と、を有するレーザシステムであって、該ファイバ増幅器で作られたパルスが放物線状であるように、該シードパルスは発生させられ、該ファイバ増幅器は、形作られる、レーザシステム。

【請求項６０】シードパルスの光源と、該シードパルスを入力し増幅し、増幅されたパルスを出力するファイバ増幅器と、を有するレーザシステムであって、そのシード光源は、該ファイバ増幅器で放物線状パルスの形成を誘起するパルスを発生する、レーザシステム。

【請求項６１】シードパルスの光源と、該シードパルスを入力し増幅し、且つ増幅したパルスを出力するファイバ増幅器と、を有するレーザシステムであって、該ファイバ増幅器で作られたパルスが放物線状であるように、該シードパルスは発生させられ、該ファイバ増幅器は、形作られる、レーザシステム。

【請求項６２】異なる波長の光パルスの光源と、該異なる波長の各々で経験したラマンシフトの度合いを動的に修正する手段と、を有する光通信サブシステム。

【請求項６３】異なる波長の光信号を搬送するファイバ光搬送器と少なくとも一つのファイバレーザ増幅器とを有するタイプの光通信システムにおける、該異なる波長の信号に異なる利得を課する少なくとも一つのラマンシフタを有する改良。

【請求項６４】パルス出力を発生するファイバレーザと、該ファイバレーザのパルス出力を入力するラマンシフタと、該ラマンシフタの出力を周波数逓倍する非線形結晶と、を有するレーザシステムのためのシード光源。

【請求項６５】前記非線形結晶は、ＰＰＬＮ、ＰＰリチウムタンタレート、ＰＰ　ＭｇＯ：ＬｉＮｂO_3、ＰＰ　ＫＴＰからなる群から選ばれた周期的にポールした強誘性光学材料と、ＫＴＰ異種同形体の周期的にポールした結晶とを有する請求項６４に請求されたシード光源。

【請求項６６】請求項６５に請求されたシード光源であって、前記非線形結晶の区間は、該シード光源のパルス出力のパルス長さを制御するために選定される、シード光源。

【請求項６７】前記非線形結晶の出力波長は、該非線形結晶の温度を制御することで制御される、請求項６５に請求されたシード光源。

【請求項６８】供給ファイバと、回折格子型パルス圧縮器と、該パルス圧縮器の３次分散を補償するためのＷ－

ファイバと、を有する放物線状パルス体制で動作するファイバレーザシステム用供給システム。

【請求項69】放物線状パルス体制で動作するファイバレーザ増幅システム用分散補償配列であって、該システムの増幅器段の前に配置され、少なくとも一つの負の3次分散生成素子を含むパルス拡張器と、該拡張器で導入された分散を取り消す正の3次分散をもち、2次分散を補償するために該増幅器段の後に配置されたパルス圧縮器とを有する分散補償配列。

【請求項70】放物線状パルス体制で動作するファイバレーザ増幅システム用分散補償配列であって、該システムの増幅器段の前に配置され、少なくとも一つの正の2次分散生成素子と3次と4次分散を生成するための少なくとも一つのブラッグファイバ回折格子およびファイバ透過回折格子を含むパルス拡張器と、該拡張器で導入された分散を取り消す正の3次分散をもち、2次分散を補償するために該増幅器段の後に配置されたパルス圧縮器とを有する分散補償配列。

【請求項71】フェムト秒体制シードパルスの光源と、ポンプパルスを形成するために該シードパルスを受けて波長シフトするラマンシフトファイバと、該ポンプパルスと反対方向に伝搬する複数の信号波長パルスを注入されたラマン増幅器ファイバと、該ポンプパルスを波長同調するためと、該ラマン増幅器のラマン利得の中心波長を同調するために、該シードパルスのパワー、波長、幅の少なくとも一つを変調する手段と、を有する波長可変ラマン増幅器。

【請求項72】請求項71に請求された増幅器であって、前記ポンプパルスは、前記信号パルスを有効な修正ラマン利得スペクトルに合わせるように、該ラマン増幅器の信号パルス横断時間以下の時間周期で波長同調される、増幅器。

【請求項73】1ナノ秒以下のパルス幅をもつパルス出力を発生するファイバレーザと、分散が、幾分か波長同調を最適化するように波長で変化するホーリファイバと、を有する波長可変レーザシステム。

【請求項74】パルス出力を発生するファイバレーザと、分散が、幾分か波長同調を最適化するように波長で変化するホーリファイバと、を有する波長可変レーザシステムであって、波長同調範囲内で、該ホーリファイバは、負の2次分散を示し、波長300nm以内で入力パルス光源に対し2次分散ゼロをもち、シリカの3次材料分散の絶対値に等しい絶対値あるいはそれ以下の3次分散を示す、波長可変レーザシステム。

【発明の詳細な説明】

【0001】

【発明の背景】1．発明の分野

この発明は、波長選択ができ、コンパクトで、モジュール式で、かつ効率的な高パワー超短レーザパルス光源に関し、この超短レーザパルス光源は、超高速レーザ技術の工業使用における基本的な構成要素である。

【0002】2．関連技術の記述

ファイバレーザは、これまで長い間、超短パルス発生用の有効な媒体を与えると認識されてきた。しかしながら、これまで、そのようなシステムは、主に、波長可変性に対して制限されたオプションをもち、かつ最小の達成可能パルス幅に限界がある、動的に波長がシフトした（チャープした）ブラッグ回折格子を使用した瞬時周波数が変化するパルス（チャープしたパルス）増幅に基づいていた（A. Galvanauskas and M.E. Fermann,'Optical Pulse Amplification using Chirped Bragg Gratings,'United States Patent,No.5,499,134）。チャープしたブラッグ回折格子は、実に広く入手できるデバイスに発達してきた。そして、ブラッグ回折格子内のチャープは、線形に、あるいはチャープパルス増幅システム内での任意のオーダの分散を補償するために、非線形に、さえもデザインされる（A.Galvanauskas et al.,'Hybrid Short-Pulse Amplifiers with Phase-MismatchCompensated Pulse Stretchers and Compressors',U.S.Patent No.5,847,863）。このチャープパルス増幅システムは、バンド幅制限パルス、すなわち、与えられたスペクトルのパルスバンド幅にとって最も短くできるパルス、の発生に重要である。

【0003】光ファイバのパワーとエネルギの限界を最大化するために、チャープパルス増幅を使用することは、明らかに望ましいが、同時に、システム集積化の要求（ブラッグ回折格子は、最も高い可能な分散を与えるために、透過よりむしろ反射で動作する必要がある）は、そのような標準的なチャープパルス増幅システムの使用を演出する。チャープパルス増幅の代わりとして、多モードファイバ増幅器での高パワーパルス増幅が提案された（M. E. Fermann and D. Harter,'Single-mode Amplifiers and Compressors Based on Multi-mode Optical Fibers',UnitedStates Patent,No.5,818,630）。また チャープパルス増幅の代わりとして、ファイバ増幅器でのソリトンラマン圧縮を使用することや、あるいは、一般的に、非線形ファイバ増幅器中でのパルス圧縮を使用することが提案された（M.E.Fermann, A.Galvanauskas and D.Harter,'Apparatus and Method for the Generation of High-power Femtosecond Pulses from a Fiber Amplifier',United States Patent,No.5,880,877）。

【0004】明らかに、多モードファイバの使用は、そのようなシステムの性能をさらに改善するために、チャープパルス増幅およびソリトンラマン圧縮と結合される。しかしながら、今日まで、全体のシステム性能をさらに最適化するためのパルス形状制御法は、全然記述されなかった。同じく、そのようなチャープパルス増幅システムの拡張器部分に自己－位相変調を使用することは、提案されていなかった。

【0005】さらに、システムのコンパクト化と高エネ

ルギ化の折衷案として、バルク光学圧縮器と合同してファイバ分散遅延ラインを使用することは、有利であり、少なくとも、高－エネルギファイバレーザシステムの部分的な集積化をもたらす（M.E.Fermann A.Galvanauskas and D.Harter:'All fiber souce of 100 nJ sub-picosecond pulse',Appl.Phys.Lett.,vol.64,1994,pp.1315-1317）。しかしながら、今日まで、バンド幅限界近くまでパルスを再圧縮するために、拡張器と圧縮器の組合せの中で、より高次の３次および４次分散を制御する有効な方法は、全然開発されなかった。

【０００６】チャープパルス増幅の代わりとして、高－利得正分散（非ソリトンを持続させる）シリカーベースの単一モードエルビウム増幅器をバルクプリズム圧縮器と組み合わせて使用することにより、有効なパルス圧縮が得られるということも以前に提案された(K.Tamura and M.Nakazawa,'Pulse Compression by Nonlinear Pulse Evolution with Reduced Optical Wave Breaking in Erbium-Doped Fiber Amplifiers,'Opt.Lett.,Vol.21,p.68(1996))。しかしながら、この技術をシリカーベースのエルビウム増幅器と合同して使用することとは、問題である、なぜなら、正分散のための要求がファイバコアサイズを約５ミクロンに制限するか、さもなければ、負の材料分散が、正の導波路分散を支配し、全体を負のファイバ分散にするからである。同様に、シリカーベースの多モードファイバは、エルビウム増幅器波長で負の分散をもち、有効なパルス圧縮のためにそれらを使用することを妨げている。このように、正分散エルビウム増幅器の限定されたコアサイズは、達成可能なパルスエネルギを大きく減少させる。

【０００７】さらに、一つのエルビウム増幅器の後で付加的なスペクトル拡大やパルス増幅を行う方法は、田村らによって示されなかった。同様に、エルビウム増幅器の分散を補償するためにプリズムパルス圧縮器の性能を最適化させる方法は、田村らによって教示されなかった。

【０００８】チャープパルス増幅の別の代わりとして、非増幅光ファイバをバルク回折格子圧縮器と合同して使用することが提案された（D.Grischkowsky et al.and J.Kafka et al.,U.S.Patent No.4,750,809)。しかしながら、そのようなシステムには利得がないので、高パルスエネルギが、高出力パワーを得るために非線形光学素子に結合されなければならず、システムのピークパワー特性を低下させる。さらに、そのような光学配置で、より高次の分散を補償する方法は議論されておらず、このアプローチの実現性を大きく制限している。さらに、そのようなシステムへの入力でのパルス形状を制御することなしで、線形チャープをもつスペクトル広がりは、非常に限定された入力パワーでのみ得られる。入力パルス形状の制御は、Kafkaらによって議論されなかった。同様に、バルク回折格子圧縮器と合同して最も短い可能なパルスを得るために、そのような非線形光学素子における２次および３次分散制御が、必要とされるが、これもKafkaらによって議論されなかった。

【０００９】別の（分散－補償）導波路素子中に色分散を使用しての（低パワー）光波信号中の色分散補償は、電気通信システムの性能を最適化するために導入された（C.D.Poole,'Apparatus of compensating chromatic dispersion in optical fibers,'US Patent No.5,185,827)。しかしながら、高－パワーパルス光源の場合、分散－補償導波路素子によって導入される自己－位相変調は、それらの有効な使用を妨げる。さらに、Pooleによって議論されたシステムは、分散－補償導波路素子中で高次モードを選択的に吸収するため、あるいは、分散－補償導波路素子中で基本モードを選択的に増幅するために、モード－変換器および、あるいは希土類添加ファイバと合同して動作するだけである。自己－位相変調の存在下での高－パワー光パルスの分散を補償する方法は、何ら教示されなかった、また、モード－変換器なしの分散－補償導波路を実施する方法は、何ら提案されなかった。

【００１０】モード－変換器と高次モードを使用する代わりとして、Ｗ－スタイルの屈折率プロファイルをもつファイバが知られている（B.J.Ainslie and C.R.Day,'A review of single-mode fibers with modified dispersion characteristics';J.Lightwave Techn.,vol.LT-4,No.8,pp.967-979,1986)。しかしながら、高－パワーファイバチャープパルス増幅システムへの、そのようなファイバデザインの使用は、議論されたことがなかった。

【００１１】超高速ファイバ増幅器の効率を最大にするために、Ｙｂファイバ増幅器の使用が提案された（D.T.Walton,J.Nees and G.Mourou,"Broad-bandwidth pulse amplification to the 10μJ level in an ytterbium-doped germanosilicate fiber,"Opt.Lett.,vol.21,no.14,pp.1061(1996))、しかしながら、Waltonらによる研究は、信号パルスの光源としてモードロックＴｉ：サファイアレーザを採用するばかりでなく、Ｙｂ添加ファイバの励起にアルゴン－レーザポンプＴｉ：サファイアレーザを採用したが、これは、非常に効率がわるく、且つ明らかに小型装置と両立しない。さらに、増幅過程で光パルスの位相を制御する方法は、何ら提案されなかった、すなわち、Ｔｉ：サファイアレーザからの１００ｆｓパルスが、１．６ｋｍの長さの単一モードファイバ分散遅延ラインを通してＹｂ増幅器に結合されたが、この遅延ラインは、システムを超高速増幅に適用することを大きく制限する高次分散による大きな位相歪みを起こす。それよりは、Ｙｂ増幅器中で高品質高パワー放物線状パルスを誘起するためには、２００－４００ｆｓの範囲のシードパルスが２．３ｍの長さのＹｂ増幅器には好ましい。Waltonらによる単一モードＹｂ添加ファイバ増幅器

の使用は、Ｙｂ増幅器のエネルギとパワーの限界をさらに大きく制限する。多モードＹｂ添加ファイバの使用は、内容がここに参考文献として組み入れられた米国出願Ｎｏ．０９／３１７，２２１に提案されたが、Ｙｂ増幅器と両立する小型超短パルス光源は、わかりにくいまま残った。

【００１２】能動的な光変調機構に組み入れられる広可変パルスＹｂ−ファイバレーザが、最近記述された（J. Porta et al.,'Environmentally stable picosecond ytterbium fiber laser with a broad tuning range',Opt.Lett.,vol.23,pp.615-617(1998)）。このファイバレーザは、おおよそＹｂの利得バンド幅内の同調範囲を設けているが、そのレーザを超高速光学に適用することとは、そのレーザで発生される比較的長いパルスにより制限される。一般的に能動モードロックレーザは、受動モードロックレーザより長いパルスを発生し、この現状のケースでは、発生したパルスのバンド幅は、５ｐｓの最小パルス幅をもち僅か０．２５ｎｍである。

【００１３】非線形結晶中での周波数変換と合同してラマン−シフトを使った広波長可変ファイバレーザ光源が、最近記述された。（M.E.Fermann et al.,US Patent No.5,880,877 and N.Nishizawa and T.Goto,"Simultaneous Generation of Wavelength Tunable Two-Colored Femtosecond Soliton Pulses Using Optical Fibers," Photonics Techn.Lett.,vol.11,no.4,pp421-423参照）。基本的に、空間的に不変なラマンシフタが提案され、その結果、波長可変範囲は３００−４００ｎｍに制限される（Nishizawa et al.参照）。さらに、ラマンシフトの継続する応用や、非線形光学結晶での非線形周波数変換に基づく高度な非線形システムのノイズを最小にする方法は、何も知られていない。さらに、西沢らによって記述されたシステムは、ラマンシフタをシードするための付加的偏光制御エルビウムファイバ増幅器で増幅された比較的複雑な低パワー偏光制御エルビウムファイバ発振器につながった。さらに、Ｅｒファイバレーザからの周波数逓倍出力のラマンシフトを可能にする方法は、何も記述されていない。

【００１４】高パワーファイバ発振器からのパルスで、あるいは、高パワーファイバ発振器からの周波数変換されたパルスで、直接シードされたラマンシフタが明らかに好ましい。そのようなファイバ発振器は、最近多モード光ファイバを使って記述された（M.E.Fermann,'Technique for mode-locking of multi-mode fibers and the construction of compact high-power fiber laser pulse sources',U.S.serial number 09/199,728）。しかしながら、ラマンシフトをその後使用したような発振器の周波数を変換する方法は、今日まで論証されたことがない。

【００１５】

【発明の要旨】したがって、本発明の目的は、モジュー

ル化しやすく、小型、広波長可変、高ピーク、高平均パワー、低ノイズ超高速ファイバ増幅レーザシステムを提供することである。

【００１６】１）短パルスシード光源、２）広バンド幅ファイバ増幅器、３）分散短パルス拡張素子、４）分散パルス圧縮素子、５）非線形周波数変換素子、６）ファイバ分配用光学部品、のような様々な容易に交換できる光学系を使用することで、システムのモジュール化を確実にすることが、発明の別の目的である。さらに、提案された任意のモジュールは、交換できる光学系の下位セットに構成され得る。

【００１７】高度に集積化された分散遅延ラインも、ダイオードレーザで直接あるいは間接にポンプされた有効なファイバ増幅器も、使用することで、システムの小型化を確実にすることが、発明の別の目的である。ファイバ増幅器の高ピークパワー特性は、放物線状あるいは他の最適化されたパルス形状を使うことで、大きく拡大される。自己位相変調と合同して、放物線状パルスは、大バンド幅、高ピークパワーパルスの発生も、良く制御された分散パルス拡張も、可能にする。高パワー放物線状パルスは、ファイバの材料分散が正である波長で動作する高利得の単一あるいは多モードファイバ増幅器で発生される。

【００１８】放物線状パルスは、自己位相変調あるいは一般的なカー効果型光学非線形性の存在下でも相当なファイバ長に沿って分配されるかあるいは伝搬され、十分に線形なパルスチャープを招く。そのようなファイバ分配あるいはファイバ伝搬ラインの端部で、パルスは、おおよそバンド幅限界まで圧縮される。

【００１９】さらに、ファイバ増幅器の高エネルギ特性は、放物線状パルスあるいは他の最適なパルス形状と合同してチャープパルス増幅を使用することで大きく拡大され、そのパルス形状は、パルス品質の劣化なしに沢山の自己位相変調を可能にする。より高度に集積化されたチャープパルス増幅システムは、バルク光学パルス圧縮器（あるいは低非線形性ブラッグ回折格子）あるいはパルス圧縮を周波数変換と結びつける周期的に色素分子の配向を揃えた（ポールした）非線形結晶を使用することで、光ファイバの高エネルギ特性を損なうことなく作られる。

【００２０】ファイバパルス拡張器とバルク光学圧縮器での分散は、調整可能な２次、３次、４次分散をもつファイバパルス拡張器を組み込むことで、４分の１のオーダの位相に適合される。調整可能な高次分散は、それ自身であるいは、線形チャープファイバ回折格子と合同して標準的な階段状屈折率分布（ステップ−インデックス）高開口数ファイバを使用することで最適化された屈折率分布をもつ高開口数単一モードファイバを使って、得られる。あるいは、高次分散は、高開口数の数モードファイバでの高次モードの分散特性を使用するか、透過

型ファイバ回折格子と合同して非線形チャープファイバ回折格子あるいは線形チャープファイバ回折格子を使用することで、制御される。調整可能な４次分散は、ファイバブラッグ回折格子、透過型ファイバ回折格子のチャープを制御し、且つ異なる割合の２次、３次、４次分散をもつファイバを使用することで、得られる。同様に、高次分散は、周期的にポールした非線形結晶を使用することで得られる。

【００２１】ファイバ増幅器は、好ましくは短パルスファイバ光源の形をした短パルスレーザ光源でシードされる。Ｙｂファイバ増幅器の場合、ラマンシフトした周波数逓倍短パルスＥｒファイバレーザ光源が、広波長可変シード光源として、実装される。１．５μｍから１．０μｍへの周波数変換のノイズを最小にするために、Ｅｒファイバレーザパルス光源の自己−制限ラマンシフトが使われる。あるいは、非線形周波数変換プロセスのノイズは、自己−制限周波数逓倍を実施することで最小化される。逓倍結晶の同調曲線の中心波長は、ラマンシフトパルスの中心波長より短い。

【００２２】ラマンシフトと周波数逓倍のプロセスは逆にすることも可能である。そこでは、Ｅｒファイバレーザは、最初に周波数逓倍され、その後８００ｎｍ前後の波長と、１μｍの波長体制用のシード光源をつくるためのより高い波長と、に対してソリトン−維持分散を与える最適化されたファイバで、ラマンシフトされる。

【００２３】Ｙｂ増幅器用の低−複雑シード光源の代わりとして、モードロックＹｂファイバレーザが使用される。ファイバレーザは、強くチャープしたパルスを作るようにデザインされ、光学フィルタが、Ｙｂ増幅器用バンド幅限界近いシードパルスを選定するために結合される。

【００２４】放物線状パルスは、十分なファイバ長に沿って伝送されるので、そのパルスは、ファイバ光学通信システムにも使用される。このシステムでは、外部パルス光源で発生された放物線状パルスが伝送される。あるいは、放物線状パルスは、伝送プロセスでも発生される。後者のケースでは、伝送システムでの光学非線形性の有害な作用が、長い、分布型、正分散光増幅器を実装することで一般的に最小化される。そのような増幅器は、少なくとも１０ｋｍの長さと１０ｄＢ／ｋｍ以下の利得をもつ。増幅器当たりの全利得は、光学非線形性の有害な作用の最小化のための放物線状パルス形成の開始を信用するために、１０ｄＢを超えるべきである。伝送ラインのチャープ補償は、ファイバ伝送線に沿ってと伝送線の端部にもチャープファイバブラッグ回折格子を使用することで、適宜実施される。光学バンド幅フィルターが、伝送したパルスのバンド幅制御のために、さらに実装される。

【００２５】光ファイバでの短パルスのラマンシフトに基づく波長可変パルス光源は、多くの応用、たとえば、

分光分析で有益である。しかしながら、電気通信システム用の波長可変ファイバラマン増幅器の製作にラマンシフトを応用することで、非常に魅力的な装置が作られる。この波長可変システムにおいて、ラマンシフトしたポンプパルスは、可変波長範囲のためにラマン利得を与え、ポンプパルスに関して赤にシフトされる。さらに、ラマン利得スペクトルの形状は、ラマンシフトしたポンプパルスを変調することで、制御される

【００２６】

【提出された実施例の詳細説明】発明の一般化されたシステム図が、図１に示される。レーザシード光源１（シードモジュール；ＳＭ）で発生されたパルスは、パルス拡張モジュール２（ＰＳＭ）に結合され、そこでパルスは、分散的に時間が拡張される。拡張されたパルスは、クラッドポンプされたＹｂファイバ増幅器３（増幅器モジュール、ＡＭ１）の基本モードに結合され、そこでパルスは、少なくとも１０倍増幅される。最後に、パルスは、パルス圧縮器モジュール４（ＰＣＭ）に結合され、そこではほぼバンド幅限界近くまで時間的に圧縮される。

【００２７】図１に示した実施例は、モジュール型で、４つのサブシステム；ＳＭ１，ＰＳＭ２，ＡＭ１３，ＰＣＭ４、からなる。サブシステムは、別の実施例に記載されたように、異なる形状にはもちろん、個別でも使用される。

【００２８】以下、議論はＳＭ−ＰＳＭ−ＡＭ１−ＰＣＭシステムに関連する。ＳＭ１は、好ましくはフェムト秒パルス光源（シード光源５）を有する。ＰＳＭは、好ましくは一本のファイバ６を有し、ＳＭとＰＳＭの間の結合は、好ましくは融着で行われる。ＰＳＭの出力は、好ましくはＡＭ１モジュール３の内部のＹｂ増幅器７の基本モードに注入される。結合は、融着、ファイバ結合器、あるいはＰＳＭ２とファイバ増幅器７の間のバルク光学結像システム、で行われる。すべてのファイバは、好ましくは偏光保持型が選択される。ＰＣＭ４は、好ましくは小型化の理由で、一つあるいは二つのバルク光学回折格子で形成される分散遅延ラインを有する。あるいは、多数のバルク光学プリズムやブラッグ回折格子がＰＣＭ４に使われる。ＰＣＭ４への結合は、図１に単レンズ８で描写されているように、バルク光学レンズシステムで行われる。ファイバブラッグ回折格子を含むＰＣＭの場合、ファイバピッグテールがＰＣＭへの結合に使われる。

【００２９】フェムト秒レーザシード光源の一例として、ラマンシフト周波数逓倍Ｅｒファイバレーザが、図２のＳＭ１ｂ内に示されている。フェムト秒レーザ９は、波長１．５７μｍで２００ｆｓパルス、繰り返し周期５０Ｈｚで１ｎＪのパルスエネルギを供給する市販の高エネルギソリトン光源（IMRA America, Inc., Femtolite B-60TM）である。

【００３０】１．５μｍから２．１μｍの波長領域への

最適なラマンシフトのために、偏光保持ラマンシフトファイバ１０の長手方向にコア径（テーパ化した）を減らすことが行われる。コア径の減少は、１．５から２．１μｍまでの全波長範囲でラマンシフタでの２次分散を零（しかし負）近くまで保つために必要とされる。２次分散の絶対値を小さく保つことで、ラマンシフタ内でのパルス幅が最小化され、このことは、ラマン周波数シフトの最大化をもたらす（J.P.Gordon,"Theory of the Soliton Self-frequency Shift,"Opt.Lett.,11,662(1986)）。テーパ化なしでは、ラマン周波数シフトは、一般に２．００μｍ前後に制限され、この２．００μｍは、周波数逓倍後でもＹｂファイバ増幅器の利得バンド幅と一致しない。

【００３１】この特別の例では、それぞれ６μｍと４μｍのコア径をもつ３０ｍと３ｍの長さのシリカ゛ラマン゛ファイバ（１．５６μｍで単一モード）からなる２段階ラマンシフタ１０が実装される。シリカの赤外吸収端の始まりが２．０μｍであることにより、ラマンシフタ１０の終端方向にテーパ化する率を増加することが有利である。現在の例では、１．５７μｍから２．１０μｍへの変換効率２５％以上が得られている。なめらかに変化するコア径をもつ、より多数のファイバを使うか、あるいはなめらかに変化するコア径をもつ単一のテーパ化ファイバを実装することで、よりよい変換効率が得られる。

【００３２】ラマンシフトしたパルスの１．０５μｍ領域への周波数変換は、適当に選定されたポーリング周期をもつ一本の周期的にポールしたＬｉＮｂＯ３（ＰＰＬＮ）結晶１１で行われる。（この仕様全てであるが、周波数変換用の好ましい材料は、ＰＰＬＮのように必要であり、他の周期的にポールしたＰＰリチウムタンタレート、ＰＰ ＭｇＯ：ＬｉＮｂＯ$_3$、ＰＰ ＫＴＰのような強誘性光学材料あるいはＫＴＰ異種同形体の周期的にポールした結晶も有利に使用されることが理解されるべきである。）ＰＰＬＮ結晶１１との結合は、図２にレンズ１２と示されたレンズシステムを使って行われる。ＰＰＬＮ結晶１１の出力は、レンズ１２で出力ファイバ１３に結合される。１μｍの波長領域で４０ｐＪ以上のパルスエネルギをもたらす２．１μｍの周波数逓倍の場合、１６％の変換効率が得られる。周波数変換されたパルスのスペクトル幅は、ＰＰＬＮ結晶１１の長さの適当な選択で選定される、たとえば、１３ｍｍの長さのＰＰＬＭ結晶は、約８００ｆｓのパルス幅に対応する１．０５μｍ領域での２ｎｍのバンド幅を生成する。発生されたパルス幅は、おおよそＰＰＬＮ結晶の長さに比例する。すなわち、４００ｆｓのパルス幅をもつ周波数変換されたパルスは、長さ６．５ｍｍのＰＰＬＮを必要とする。このパルス幅縮小は、周波数変換されたパルス幅が、約１００ｆｓに達するまで続けられ、ラマンシフトしたパルスの制限された１００ｆｓのパルス幅は、さらなるパルス幅の減少を制限する。

【００３３】さらに、周波数変換されたパルス幅がラマンシフトしたパルスのパルス幅より十分長いとき、ラマンパルスの広いバンド幅は、周波数変換されたパルスの波長同調を可能にするために活用される。すなわち、有効な周波数変換は、周波数で２（ω１－δω）から２（ω１＋δω）までのパルス範囲にとって得られる。ここで、２δωは、ラマンシフトしたパルスのスペクトルの最大値の半分でのスペクトル幅である。ここでの連続波長同調は、周波数変換結晶１１の温度を調節することで簡単に行われる。

【００３４】ラマンシフタ、ＰＰＬＮ結晶の組み合わせ、の増幅されたノイズは、次のように最小化される。Ｅｒファイバレーザパルス光源の自己制限ラマンシフトは、ラマンシフトをシリカベースの光ファイバでの２μｍより大きい方に拡張することで使用される。２μｍ以上の波長の場合、シリカの赤外吸収端がパルスを大きく減衰し始め、ラマンシフトの制限や増幅変動の減少をもたらす。すなわち、１．５μｍでの増加したパルスエネルギは、より大きなラマンシフトや２μｍの波長領域でのより大きな吸収に移るのに役立ち、この増加は、したがってこの領域でのラマンシフトしたパルスの振幅を安定させる。

【００３５】あるいは、非線形周波数変換プロセスのノイズは、自己制限周波数逓倍を行うことで最小化され、その場合、逓倍結晶の同調曲線の中心波長は、ラマンシフトしたパルスの中心波長より短い。再び、１．５μｍ領域での増加したパルスエネルギは、より大きなラマンシフトに移り、減少した周波数変換効率を引き起こし、したがって、周波数逓倍したパルスの振幅が安定化される。したがって、一定の周波数変換されたパワーは、入力パワーの大きな変化に対して得られる。

【００３６】これが図３に示されおり、ここで、１μｍ波長領域での周波数変換された平均パワーが、１．５６μｍでの平均入力パワーの関数として示されている。自己－制限周波数逓倍は、図３にも示すように、１μｍの波長領域での周波数シフトが１．５６μｍの波長領域での平均入力パワーに依存しないということを確実にもする。

【００３７】ＰＳＭ２にはいくつかの選択できる物がある。図１に示すように、ＰＳＭとして一本のファイバ（拡張ファイバ）が使用されるとき、システムからバンド幅限界に近いパルスを得るために、適当な分散遅延ラインがＰＣＭ４に使用される。しかしながら、ＰＣＭ４の分散遅延ラインが、図４に示すようにバルクの回折格子１４から構成されると、かなりの問題が生じる。２次と３次の比｜３／２｜次分散は、１μｍの波長領域で動作する典型的な階段状屈折率分布光ファイバでの２次と３次の比｜３／２｜次分散に比べて、回折格子型分散遅延ラインで１－３０倍大きい。さらに、１μｍの波長領

域で動作する低開口数をもつ標準的な階段状屈折率分布ファイバの場合、ファイバでの３次分散の符号は回折格子型分散遅延ラインでの符号と同じである。このように、回折格子型拡張器と合同してファイバ拡張器は、システムでの３次および高次分散の補償ための予備手段にならない。

【００３８】１０倍以上のパルス拡張を行うためには、３次および高次分散の制御が、ＰＣＭ４での最適なパルス圧縮に重要になる。この問題を打破するために、ＰＳＭ２の拡張ファイバ６が、Ｗ状多クラッド屈折率分布をもつファイバ、すなわち、‘Ｗ－ファイバ’（B.J.Ainslie et al）あるいはホーリファイバ（T.M.Monroe et al.,'Holey Optical Fibers'An Efficient Modal Model, J.Lightw.Techn.,vol.17,no.6,pp.1093-1102）と置き換えられる。Ｗ－ファイバとホーリファイバの両方は、２次、３次、および高次の分散の調整可能な値を許可する。Ｗおよびホーリファイバで可能な小さいコアサイズにより、標準的な単一モードファイバでの値より大きな３次分散の値が得られる。実装は、図１に示されているのに類似しており、別々には表示されない。そのようなシステムの優位性は、ＰＳＭが純粋に透過型で動作するということである。すなわち、ＰＳＭは反射型で動作する分散ブラッグ回折格子の使用を避け、異なるシステム構成のためにシステムの中および外に接続される。

【００３９】２次、３次、および４次分散の調整可能な値をもつ別のＰＳＭ２が図５に示されている。ＰＳＭ２０ａは、通常の階段状屈折率分布光ファイバが、正、ゼロ、あるいは、負いずれかの３次分散を作ることができるという原理に基づいている。ファイバでの最も高い３次分散の値は、ファイバの最初の高次モード、カットーオフ近くのLP_{11}モード、を使うことで作られる。図５で、ＰＳＭ２０ａの４次と３次分散は、パルス拡張ファイバの３区間１５、１６、１７を使うことで、調整される。最初の拡張ファイバ１５は、ゼロの３次と適切な４次分散をもつ一本のファイバである。最初の拡張ファイバ１５は、２番目の拡張ファイバ１６に接続され、全チャープパルス増幅システムはもちろん、回折格子圧縮器の３次分散を補償するために選定される。LP_{11}モードの３次分散の優位性を確保するために、最初の拡張ファイバ１５は、２番目の拡張ファイバ１６と互いのファイバ中心でオフセットをもって接続され、２番目の拡張ファイバ１６でのLP_{11}モードの主な励起をもたらす。２番目の拡張ファイバ１６での３次分散の値を最大化するためには、高開口数ＮＡ＞０．２０をもつファイバが望ましい。３番目の拡張ファイバ１７の基本モードの後にLP_{11}モードを伝搬させるために、２番目の拡張ファイバ１６の端部で、類似の接続技術が使われる。ファイバの適切な選定によって、全増幅器、圧縮器の４次分散が最小化される。３番目の拡張ファイバ１７は、無視できる分散をもち、短くできる。

【００４０】光学的なモード変換器の使用なしでLP_{11}モードからLP_{01}モードへのパワー伝搬を行うことで受ける避けられない５０％あるいはそれ以上の損失により、全ファイバ拡張器アッセンブリの伝搬損失は、少なくとも２５％である。２番目の拡張ファイバのLP_{01}モードの残余のエネルギは、図５に示すように、選択できる反射型ファイバ格子１８で反射される。基本モードと次の高次モードとの間の有効屈折率の大きな差により、二つのモード間で回折格子共鳴波長が１０－４０ｎｍの間変化し、１０－４０ｎｍの間のスペクトル幅をもつパルスのために一方のモードを他方に対して選択的に排除することを許容する。

【００４１】ファイバ拡張器アッセンブリのエネルギ損失は、３番目の拡張ファイバ１７をＹｂ増幅器に同調させることで、小さくされる。この実施は、別々には示されない。

【００４２】４次分散が大きくないとき、最初の拡張ファイバ１５は取り除かれる。３次と４次分散が最初と２番目の拡張ファイバの間で異なりさえすれば、４次分散もゼロでない３次分散をもつ最初の拡張ファイバを使用することで、補償される。

【００４３】ＡＭ１３の内部のＹｂ添加ファイバは、Ｙｂ添加レベルが２．５モル％で、長さが５ｍである。単一モードおよび多モード両方のＹｂ添加ファイバが使用され、出力ビームの空間的品質を最適化するために、多モードファイバの場合基本モードが励起されるが、ファイバのコア径は、１－５０μｍ間変えられる。必要とされる利得の値に依存して、異なる長さのＹｂ添加ファイバが使用される。最も高い可能なパルスエネルギを発生させるために、長さ１ｍのＹｂファイバが実装される。

【００４４】パルス圧縮は、ＰＣＭ４で行われる。ＰＣＭ４は、通常のバルク光学部品（図４に示すバルク回折格子対のような）、単一回折格子圧縮器、あるいは、多数の分散プリズムやその他の分散遅延ラインを含む。

【００４５】あるいは、ファイバやバルクブラッグ回折格子あるいはチャープした周期的にポールした結晶が使用される。チャープした周期的にポールした結晶は、パルス圧縮と周波数逓倍の機能を結びつけ（A.Galvanaskas,et al.,'Use of chirped quasi-phase matched materials in chirped pulse amplification systems'U.S.Application No.08/822,967,その内容は、ここに参考文献で具体化されている）、独自のコンパクトなシステムのために伝搬供給するように動作する。

【００４６】本発明に対する他の変更や修正は、これまでの開示や教示からの技術に熟練したものに明白である。

【００４７】特に、ＳＭ１は、周波数領域１．５２－２．２μｍのバンド幅近くに限定されたフェムト秒パルスを作るための自立ユニットとして使われ、非線形結晶での周波数変換後に周波数領域７６０ｎｍ－１．１μｍ

のパルスを作るのにも使われる。周波数領域は、フッ化ラマンシフトファイバあるいはシリカより長い赤外吸収端をもつ他の光ファイバを使うことでさらに拡大される。この技術を使って、約３－５μｍ以上の波長が達成される。周波数逓倍と共に、７６０ｎｍから５０００ｎｍ、までの連続同調が達成される。２μｍ領域のパルスパワーは、ＴｍあるいはＨｏ添加ファイバを使うことで、さらに高められる。そのような増幅器で、バンド幅限界近くの１０ｎＪを超えるパルスエネルギをもつラマン－ソリトンパルスが、２μｍの波長領域の単一モードファイバに供給される。周波数逓倍後、数ｎＪのエネルギをもつフェムト秒パルスが、分散パルス圧縮器の使用なしで、１μｍ領域で得られる。そのようなパルスは、大きなコアの多モードＹｂ増幅器のために高エネルギシードパルスとして使用され、多モードＹｂ増幅器は、増幅された自然放出を抑えるために単一モードＹｂ増幅器より高いシードパルスエネルギを必要とする。

【００４８】シリカラマン－シフタ２０、Ｔｍ添加増幅器２１および第２のフッ化ガラスベースラマンシフタ２２をもつＥｒファイバレーザパルス光源１９と組み合わせた超広波長可変ファイバ光源の一例が図６のＳＭ１ｃに示されている。選択できる周波数逓倍器は示されていない；最適な安定性のために、全てのファイバは偏光保持でなければならない。Ｅｒファイバレーザパルス光源に代わる別のものとして、Ｅｒ増幅器をもつダイオードレーザパルス光源の組合せが使われる；これは分離して示されない。

【００４９】ＳＭの別の代わりとして、ＳＭ１ｄが図７に示されており、ラマンシフトホーリファイバ２４と合同して周波数逓倍高パワー受動型モードロックＥｒあるいはＥｒ／Ｙｂファイバ発振器２３を有する。ここで、１．５５μｍの波長領域で動作する発振器２３からのパルスは、周波数逓倍器２５とレンズ系２６を使って最初に周波数逓倍され、その後周波数逓倍されたパルスは、７５０ｎｍ以上の波長あるいは少なくとも８１０ｎｍ以上の波長に対してソリトン維持分散を与えるホーリファイバ２４でラマンシフトされる。１μｍ波長帯あるいは１．３、１．５．２μｍ波長帯でラマンシフトしたパルスを増幅し、且つ異なるデザインのラマンシフトファイバを選定することで、波長領域が約７５０ｎｍから５０００ｎｍの間で動作する連続的に可変な光源が作られる。多数の付属増幅器２７をもつそのような光源のデザインも図７に示されている。

【００５０】最適なラマン自己－周波数シフトのために、ホーリファイバ分散が、波長の関数として最適化されなければならない。ホーリファイバの３次分散の絶対値は、シリカの３次材料分散の絶対値以下か、あるいは等しくなければならない。これは、２次分散の値が負でなければならず、２次分散ゼロがシード入力波長で３００ｎｍ以内でなければならないからである。

【００５１】Ｙｂ増幅器用シード光源の別の代替物として、反ストークスファイバでの反ストークス発生が使用される。反ストークス発生後、広い波長可変光源を作るために、付加的長さのファイバ増幅器とラマンシフタが使用される。一般的な構成は、図７に示されているものに類似している。ここで、周波数逓倍手段２５は省略され、ラマンシフタ手段２４は反ストークス発生手段と置き換えられる。たとえば、１．５５μｍで動作するＥｒファイバレーザシード光源を使った反ストークス発生手段で１．０５μｍ波長帯の光を効率よく発生するためには、小さいコアと低い値の３次分散をもつ光ファイバの形をした反ストークス発生手段が最適である。３次分散の低い値は、ここでは、１．５５波長領域での標準的な電子通信ファイバの３次分散の値に比べて小さい３次分散の値と定義される。さらに、反ストークスファイバの２次分散の値は、負でなければならないＹｂ増幅器の別の代替シード光源として、受動モードロックＹｂあるいはＮｄファイバレーザがＳＭ内部に使用される。好ましくは、負分散で動作するＹｂソリトン発振器が使用される。Ｙｂソリトン発振器を作るために、図８に示すように、出力ファイバ３６に接続されたチャープファイバ格子２９によって負共振器分散が共振器内に導入される；あるいは、ホーリファイバ（T.Monroe,et al）のような負分散ファイバがＹｂソリトンレーザ共振器に使用される。そのような配列を具体化するＳＭが、図８中に１ｅとして示されている。ここで、Ｙｂファイバ３０は、偏光保持で、偏光子３１がファイバ（結合がレンズ３２で達成されている）の一つの軸に沿う発振を選ぶために組み入れられる。簡単のために、Ｙｂファイバ３０は、図８に示すように、側方からクラッドポンプされる。しかしながら、通常の単一モードファイバを組み入れる受動モードロックＹｂファイバレーザも使われる。そのような配列は別々に示されていない。回折格子３５は、分散制御のために使用され、また、内部共振器ミラーとして使用される。ポンプダイオード３３は、Ｖ溝３４を通してポンプ光を供給する。

【００５２】ホーリファイバを組み入れる配列は図８に示したシステムとほとんど同じであり、ここで付加的なホーリファイバは共振器のどこかに接続される。ホーリファイバを組み入れる場合、ファイバブラッグ回折格子は負分散をもつために不要であり、同様にブラッグ回折格子は誘電体ミラーで置き換えられる。

【００５３】実施するのに最も簡単なものは、しかしながら、正分散で動作するＹｂ発振器であり、それは、共振器分散を制御するために負分散ファイバブラッグ回折格子あるいは、ホーリファイバのような特別の共振器要素を必要としない。”放物線状”Ｙｂ増幅器（あるいは通常のＹｂ増幅器）と共に、高パワーＹｂ増幅器システムのための非常にコンパクトなシード光源が得られる。Ｙｂ増幅器４０をもつそのようなＹｂ発振器が図９に示

されており、ここで、好ましくは、Ｙｂ増幅器４０は後に詳論するような"放物線状"Ｙｂ増幅器である。図８中と同じ要素には同じ番号が付与されている。

【００５４】図９の中のＳＭ１ｆは、図８に関して記述されたような側方ポンプＹｂ増幅器４０を有するが、他のポンピング配列も実装されている。Ｙｂファイバ４４は、当然偏光保持で、偏光子３１が単一の偏光状態を選ぶために挿入される。ファイバブラッグ回折格子３７は、Ｙｂの利得バンド幅に比べ小さな反射バンド幅をもち、Ｙｂの利得バンド幅に比べ小さなバンド幅をもつパルスの発振を確実にする。ブラッグ回折格子３７はチャープされるか、あるいはチャープされない。チャープされないブラッグ回折格子の場合、Ｙｂ発振器内で発振するパルスは、正にチャープされる。Ｙｂ発振器内でのパルス発生あるいは受動モードロックは、過飽和吸収体２８で始められる。光ファイバ３９は付加的で、Ｙｂ増幅器４０に送り出されたパルスのバンド幅をさらに制限する。

【００５５】ＳＭ１ｆ内のＹｂ増幅器４０内の放物線状パルスの形成を最適化するために、入力パルスはＹｂの利得バンド幅に比べ小さいバンド幅をもつべきである；またＹｂ増幅器４０への入力パルス幅は、出力パルス幅に比べ小さくなければならないし、Ｙｂ増幅器４０の利得はできるだけ高く、すなわち、１０以上でなければならない。また、Ｙｂ増幅器４０内の利得飽和は小さくなければならない。

【００５６】放物線状増幅器の一例として、長さ５ｍのＹｂ増幅器が使用される。放物線状パルスの形成は、約０．２－１ｐｓのパルス幅と３－８ｎｍのスペクトルバンド幅とをもつシード光源を使用することで確実にされる。放物線状パルスの形成は、Ｙｂ増幅器４０内でシード光源のバンド幅を約２０－３０ｎｍまで広げるが、出力パルスは、約２－３ｐｓに広げられる。放物線状パルス内でのチャープが高度に線形であるので、圧縮後に１００ｆｓオーダのパルス幅が得られる。標準的な超高速固体増幅器が自己位相変調からの非線形位相シフトをｐｉ（最近の技術で良く知られた）と同じ大きさだけ許すので、放物線状パルスファイバ増幅器は、１０＊ｐｉおよびそれ以上の大きさの非線形位相シフトを許すことができる。簡単のために、我々はＹｂ増幅器を放物線状増幅器と呼ぶ。放物線状増幅器は単純な縮尺則に従い、増幅器長を適当に増やすことで、１ｎｍあるいはそれ以下のスペクトルバンド幅をもつ放物線状パルスの発生を可能にする。たとえば、約２ｎｍのスペクトルバンド幅をもつ放物線状パルスが、約１００ｍの長さの放物線状増幅器を使用することで発生される。

【００５７】放物線状パルスが自己変調の大きな値と、パルスの中断を招くことなしのスペクトル拡張の大きな値とを許すことができるので、放物線状増幅器のピークパワー能は、標準的な増幅器に比べ大きく高められる。これは次のように説明される。長さＬの光ファイバでの自己位相変調で受けた時間依存位相遅れ$\Phi_{nl}(t)$はピークパワーに比例する。すなわち、

$$\Phi_{nl}(t) = \gamma P(t) L,$$

ここで、Ｐ（ｔ）は光パルス内での時間依存ピークパワーである。周波数変調は位相変調の導関数で与えられ、すなわち、$\delta\omega = \gamma L[\partial P(t)/\partial t]$。放物線状パルスプロファイル$P(t) = P_0[1-(t/t_0)^2]$、ここで、$(-t_0 < t < t_0)$の場合、周波数変調は線形である。それで、実にパルスプロファイルも放物線状のままであり、線形周波数変調だけをもつ大きなピークパワーの発生と線形パルスチャープの発生とを可能にすることが、示されている。

【００５８】Ｙｂ増幅器４０で発生されたチャープパルスは、図４に示すような回折格子圧縮器を使って圧縮される。あるいは、チャープした周期的にポールした結晶４２とレンズ４１が、図９に示されるように、パルス圧縮のために使われる。図９に示すＳＭ１ｆと関連して、約５３０ｎｍのグリーンスペクトル領域でのフェムト秒パルスを出す非常にコンパクトな自立光源が得られる。

【００５９】図９に示す受動モードロックＹｂファイバレーザ４４のほかに、Ｙｂ増幅器にシードするために別の光源も使われる。これら別の光源は、ラマンシフトＥｒあるいはＥｒ／Ｙｂファイバレーザ、周波数シフトＴｍあるいはＨｏファイバレーザおよび、ダイオードレーザパルス光源を有する。これら別の実装物は別々に示されない。

【００６０】図１０でファイバ供給モジュール（ＦＤＭ）４５が図１に示す基本システムに加えられる。この場合ＰＳＭ２は除かれる；しかしながら、増幅モジュールのピークパワー能を高めるためにＰＳＭ２は必要なとき含まれる。図１０に示すＹｂ増幅器７は非放物線状、放物線状の両方で動作できる。

【００６１】最も簡単な構成では、ＦＤＭ４５が一本の光ファイバ４６（供給ファイバ）からなる。放物線状増幅器の場合、供給ファイバ４６はパルス品質での損失を招くことなくＹｂ増幅器７に直接接続される。むしろ、放物線状パルスプロファイルにより、沢山の自己位相変調の場合でも、ＰＣＭ４でのさらなるパルス圧縮を可能にするパルスに近似的に線形なチャープが付加される。ＰＣＭ４は、図４に示す小寸法バルク回折格子圧縮器１４を使って供給ファイバと共にＦＤＭ４５に集積化される。この場合、適当なコリメートレンズと接続する供給ファイバは、図４に示す入力と置き換えられる。そのような実施の別々の図は示されてない。しかしながら、ＰＣＭ４の使用は付随的で、たとえば、チャープ出力パルスがシステムから要求されるなら、省かれる。ＰＣＭ４と共に、図１０に記載されたシステムは、派生的なチャープパルス増幅システムを構成し、ここで、パルスが時間に関して分散的に広げられる間、利得はもちろん自己

位相変調も加えられる。通常のチャープパルス増幅システムに自己位相変調を付加することは，一般的にパルス圧縮後に大きなパルス変形をもたらす。放物線状パルスの使用はこの制限を打破する。

【００６２】次世代ファイバ光通信システムは，チャープパルス増幅システムと解釈される（，たとえば，D.J. Jones et al.,IEICE Trans.Electron .,E81-C,180(1998)参照）。明らかに、放物線状パルスによるパルス変形の最小化は、光通信システムに等しく関連する。

【００６３】５０ｆｓより短いパルス幅を得るためには，ＦＤＭモジュールあるいは光ＰＳＭ内の３次および高次の分散の制御が重要になる。ＰＳＭでの高次分散の制御は、図１と５に関連して既に議論された；ＦＤＭの高次分散の制御は、非常に類似しており、図１１に示すＦＤＭ４５ａの模範的な実施例で議論される。図１に丁度示すように，大きな３次分散のＷ－ファイバがバルクＰＣＭ４の３次分散を補償するために使用される。図５に丁度示すように、ＦＤＭの高次分散に対して異なる値をもつファイバ１５，１６，１７を使うことで，バルク回折格子を有するＰＣＭ４を含む全システムの高次分散が補償される。

【００６４】ＰＳＭの別の実施例が図１２及び図１３に示されており，それらはＰＳＭに市場で入手できる線形チャープファイバブラッグ回折格子を使用できるようにするような実際的な同じ値をもち，ＰＣＭもＰＳＭも有する全チャープパルス増幅システムの高次分散を補償する。別の代替物として、非線形チャープファイバブラッグ回折格子もＰＣＭの分散を補償するためにＰＳＭに使用される。そのような配列は分離して示されていない。

【００６５】Ｗ－ファイバの使用あるいはＰＳＭでのＬＰ$_{11}$モードを避けるために、図１２に示すようなＰＳＭの別の実施例がＰＳＭ２ｂとして示されている。ここで負の線形チャープブラッグ回折格子４７が、負の３次分散をもつ単一モード拡張ファイバ４８とサーキュレータ４９と接続して使用される。負の線形チャープブラッグ回折格子の導入は、ＰＳＭ２ｂでの比（３次／２次）分散を増大させ，バルク回折格子圧縮器が使用されるとき，ＰＣＭ４での３次分散の高い値の補償を可能にする。ＰＳＭ２ｂは、ＰＳＭの複雑さをさらに改善するために線形チャープファイバブラッグ回折格子と接続したＷ－ファイバを含むこともできる。

【００６６】高次分散補償用ＰＳＭの別の実施例として，図１３に配列がＰＳＭ２ｃとして示されており、それは，正の線形チャープファイバブラッグ回折格子４９，サーキュレータ５０，および別のファイバ透過型回折格子５１を有する。ここで、ＰＣＭモジュール内の線形および高次分散を補償するために，正の線形チャープファイバブラッグ回折格子４９は、正の２次分散を作り，他のファイバ透過型回折格子５１は、適当な値の付加的な２次、３次、４次分散を作る。一つ以上のファイバ透過型回折格子あるいはファイバブラッグ回折格子が，３次、４次およびできればより高次の分散の適当な値を得るために使用される。

【００６７】Ｙｂ増幅器からの増幅されたパルスエネルギをｍＪのオーダおよびそれ以上まで増大させるために，パルス採集素子とさらなる増幅段が図１４に示すように実装される。この場合，パルス採集器５２は最初の増幅段ＡＭ１　３ａと２番目の増幅段ＡＭ２　３ｂの間と，ＰＳＭ２と最初の増幅モジュールＡＭ１　３ａの間とに挿入される。任意の数の増幅器とパルス採集器が、最も高い可能な出力パワーを得るために使われ，ここで，最後の増幅段は好ましくは、多モードファイバからなる。回折限界出力を得るために、多モード増幅器の基本モードが選択的に励起され，よく知られた技術（M.E. Fermann et al.,United States Patent,No.5,818,630）を使ってガイドされる。パルス採集器５２は、一般的に音響－光学あるいは電気－光学変調器のような光変調器からなるように選択される。パルス採集器５２は，ＳＭから出てくるパルスの繰り返し周期を与えられた値（たとえば、５０ＭＨｚから５ＫＨｚへ）だけ低下させ、平均パワーは小さいままで非常に高いパルスエネルギの発生を可能にする。あるいは，直接スイッチできる半導体レーザも、システムの繰り返し周期を任意の値に固定するために使用される。さらに、後方の増幅器段に挿入されたパルス採集器５２も増幅器での増幅された自然放出の増強を抑え，高エネルギ超短パルスに出力パワーを集中させることを可能にする。増幅段は，以前議論したようなＰＳＭやＰＣＭと合致しており，ここでは，全システムの分散がシステムの出力で最も短い可能なパルスを得るために最小化される。

【００６８】増幅器モジュールＡＭ１　３ａは，放物線状スペクトルをもつパルスを生成する放物線状増幅器のようにデザインされる。同様に、ＡＭ１　３ａからの放物線状パルスは，図１４にも示されるようなパルス成形あるいはパルス拡張ファイバ５３で放物線状パルススペクトルをもつパルスに変換され、ここで、自己位相変調と正分散の相互作用がこの変換をうまく行う。これは理解されるであろう、なぜなら、放物線状パルスプロファイルをもつチャープパルスが一本のファイバ中で放物線状スペクトルをもつ放物線状パルスに進化することができるからである。放物線状パルス形状は、次の増幅段でかなりの自己位相変調の量を最大化し，順番に，ＰＳＭ２とＰＣＭ４で必要とされる分散パルス拡張と圧縮の量を最小化する。同様に、放物線状パルス形状は，大きなパルス変形なしに、ＰＳＭ２での十分な量の自己位相変調を許容することを認める。

【００６９】一度パルスが拡張されると、次の増幅器での自己位相変調の有害な影響は、平らなパルス形状を使うことで最小化される。平らなパルス形状は、平らなパルススペクトルを生成するために、図１４に示すような

光振幅フィルタ５４を最後の増幅モジュールの前に挿入することで生成される。平らなスペクトルは、十分なパルス拡張の後、本当に平らなパルスに変換される、なぜなら、十分なパルス拡張の後のスペクトル含有量と時間遅れの間には直接の関連があるからである。自己位相変調の値が１０＊πと同じ大きさでも、大きなパルス変形を招くことなく平らなパルス形状に対して許容される。

【００７０】図１４に示すような振幅フィルタも、増幅器でのパルススペクトルの再形成が無視できるとき、すなわち、放物線状パルスが発生される体制の外側に、自己位相変調器で強くチャープしたパルスに対する増幅器チェーンでの高次分散を制御するために使用される。この場合、自己位相変調は、かなりの量の次式で表される高次分散を生成する：

$\beta_n^{SPM} = \gamma P_0 L_{eff}\,[d^n S(\omega)/d\omega^n]_{\omega=0}$,

ここで、P_0はパルスのピークパワーであり、$S(\omega)$は規格化されたパルススペクトルである。L_{eff}が有効非線形長で、$L_{eff} = [\exp(gL) - 1]/g$、ここで、Ｌは増幅器長で、$g$は単位長さ当たりの増幅器利得である。したがって、図１４に示すような振幅フィルタで強くチャープしたパルスのスペクトルを正確に制御することで、任意の量の高次分散がチャープパルス増幅システムでの高次分散の値を補償するために導入される。それは、約１ｎｓに拡張した５００ｆｓパルスに対して本当に示された、～１０πの位相シフトは、１８００本／ｍｍの溝をもつバルク格子からなるバルク圧縮器（図４に示すような）の３次分散を補償するために十分である。魅力的な制御性のよい振幅フィルタは、たとえば、ファイバ透過型回折格子であるが、任意の振幅フィルタが、パルススペクトルを制御するために、高次分散を引き起こす増幅器の前に使用される。

【００７１】パルス採集器をもつ増幅器モジュールの組合せに対する別の実施例として、図１５に示す構成が使用される。非常に高いエネルギのパルスは、それらの増幅のために大きなコアの多モードファイバを必要とするので、シングルーパスの偏光保持ファイバ増幅器で基本モードを制御することは困難である。この場合モード結合を最小化するためと高品質の出力ビームを得るために、高度に中心対称の非偏光保持ファイバ増幅器を使うことが好ましい。そのような増幅器から決定論的な環境に対して安定な偏光を得るために、図１５に示すようなダブルーパス構成が要求される。ここで、単一モードファイバ５５が増幅器５６の最初のパスの後に空間モードフィルタとして使用される；あるいは、ここに開口が使用される。空間モードフィルタ５５は、多モード増幅器５６の最初のパスの後のモードを綺麗にし、多モード増幅器の達成可能な利得を制限しがちな高次モードの増幅された自然放出を抑える。レンズ６０は、増幅器５６の中と外に空間モードフィルタ５５、およびパルス採集器５２ａ、５２ｂを結合するために使用される。ファラディ回転子５７は、後方伝搬光が前方伝搬光と直交するように偏光されることを確実にし、後方伝搬光は、図示した偏光ビームスプリッタ５８でシステムの外に出される。システムの効率を最適化するために、システムの入力部で多モードファイバ５６の基本モードに回折限界近い光源が結合され、ここで、利得ガイドが多モードファイバで増幅されたビームの空間的品質をさらに改善するために使用される。ＳＭから供給されるパルス列繰り返し周期を小さくするためと多モード増幅器での増幅された自然放出を抑えるために、第１光変調器５２ａが多モード増幅器の最初のパスの後に挿入される。理想的な場所は図示するように反射ミラー５９の前である。結果として、６０－７０ｄＢの大きさのダブルーパス利得がそのような構成で得られ、ｐＪエネルギをもつシードパルスをｍＪエネルギレベルまで増幅することから要求される増幅段の数を最小化する。この種の増幅器は、以前議論したようなSM_5、PSM_5およびPCM_5と完全に合致し、ｍＪのエネルギをもつフェムト秒パルスの発生を可能にする。高利得増幅器モジュール構築の別の代替物として、ＳＭで供給されるパルス列の繰り返し周期を低下させることが、図１５に示すような増幅器モジュールに注入する前に、付加的な第２変調器５２ｂで行われる。第１変調器５２ａの透過窓の繰り返し周期は、第２変調器５２ｂの透過窓の繰り返し周期と同じかそれより低くなければならない。そのような構成は、別々には示されていない。図１５は、ここに参考文献として添付された米国特許５，４００，３５０の図５といくつかの類似性を共有する。

【００７２】本発明の別の実施例として、長い分布屈折率型正分散増幅器６１での放物線状パルスの形成を使う光通信システムが図１６に示されている。分散補償素子６３が、ファイバ光増幅器の間に挿入される。光学フィルタ６２が増幅器でのパルス形成プロセスを最適化するために、さらに実装される。光フィルタは、繰り返し透過スペクトル特性をもつように、限定された自由スペクトル範囲をもつ光学エタロンに基づいており、波長分割多重で要求されるような多波長チャンネルの同時透過を可能にする。

【００７３】キーとなる有利なことは、ファイバ透過システムの光カー非線形性で導入されるチャープを線形化するために、長い正分散ファイバの大きな利得を組合せることである。したがって、一般に、光通信システムの透過特性は、正分散（非ソリトン支持）増幅器を実装することで、改善される。そのような増幅器は、少なくとも１０Ｋｍの長さをもち、１０ｄＢ／Ｋｍ以下の利得をもつ。光学非線形性の有害な効果を最小化するための放物線状パルス形成の始まりを利用するために、増幅器当たりの総合利得は１０ｄＢを超えることができる。さらなる改善は、３ｄＢ／Ｋｍ以下の利得をもち、総合利得

が２０ｄＢ以上であるように全長を長くした増幅器を使うことで増進される。ファイバ透過ラインの透過特性のさらなる改善は、ファイバ透過ラインの負分散素子のカー非線形性の量を最小化することで得られる。これは負分散素子のためにチャープファイバ回折格子を使用することで達成される。

【００７４】透過ラインでの放物線状パルスの形成に加えて、外部光源で放物線状パルスを発生させること、そしてそれらを非ソリトン支持増幅器ファイバに注入することも有利である。そのようなシステムを有効に使用するために、ホーリファイバで可能にされた低損失正分散透過が有益である。ファイバ透過ラインに沿ってとファイバ透過ライン端とに分散補償素子が実装される。そのようなシステムの実施は、図１６に示すものに類似しており、別々には示されていない。上述のような類似のラインに沿ってデザインされた光通信システムは、ここに参考文献として添付された暫定出願Ｎｏ．００００００に開示されている。

【００７５】電気通信領域における本発明の別の実施例として、波長可変ラマン増幅器がラマンシフトパルスを使って構築される。与えられたポンプ波長の高パワー光信号がポンプ波長に関してレッドシフトした信号波長のラマン利得を作るということは、最近の技術でよく知られている。事実、それは、ここで議論された波長可変パルス光源の構築に使用されるポンプパルス自身に作用する効果である。

【００７６】波長可変ラマン増幅器の一般的なデザインが図１７に示されている。ここで、短い光パルスはシード光源で作られる。シードパルスは変調器６５で光学的に変調され、光増幅器６６で増幅される。シードパルスは次に一本のラマンシフトファイバ６７に注入される。ラマンシフトファイバは一本のホーリファイバあるいはその他のデザインのファイバである。ラマンシフトパルス間の時間周期は、図１７に示すようなパルス分割手段（ポンプパルス分割器）６８を使って減少される。このパルス分割手段は、たとえば、不均衡なマッハーツェンダ干渉計のアレイであるが、単一パルスからパルス列を発生させる任意の手段が受け入れられる。適当に波長シフトした増幅され変調されたシードパルスは、ラマン増幅器６９に注入されるポンプパルスを含み、信号入力７０で動作し、信号出力７１を作るために、図１７に示すように、ラマン増幅器で信号波長の光利得を発生する。

【００７７】ラマン増幅器ファイバ内で、信号波長での光信号は、ラマン増幅器のポンプパルスと反対方向に伝搬する。いくつかの信号波長も信号結合器を使ってラマン増幅器に注入され、そのような増幅器を光波長分割多重に合致するようにする。たとえば、波長１４７０ｎｍのポンプパルスは、シリカファイバ中で１５６０ｎｍの波長領域近辺でのラマン利得を生成する。ラマン増幅器の利得を最適化するために、ホーリファイバあるいは相

対的に小さいファイバコアをもつその他のファイバが使用される。

【００７８】ラマン利得が得られる波長の中心波長は、ポンプパルスの波長を同調することで同調される。ポンプパルスの波長同調は、ラマンシフタファイバ６７に注入される前にシードパルスの幅とパワーとを変調することで達成される。

【００７９】さらに、ラマン増幅器の利得スペクトルはポンプパルスの波長を高速に同調することで調整され、信号パルスは、有効に変更されたラマン利得スペクトルに合わされる。有効なラマン利得が時間に依存しないことを確かめるために、ポンプパルスを同調するスピード、すなわち、必要な波長範囲にわたってパルスを同調するのにかかる時間周期は、信号パルスがラマン増幅器ファイバ６９を移動するのに要する時間に比べて小さくされなければならない。

【００８０】このように、電気通信システムのラマン増幅器にとって、単一パルスからできる利得より広いスペクトル利得を得ることが有利である。異なる波長で伝搬される変化するデータ量を補償するために、ＷＤＭ電気通信システムの利得を動的に変えることができることも有利である。スペクトル利得を広げる一つの方法は、通信ファイバを伝搬する時間に比べてポンプ波長を早く同調することである。利得は、ポンプが異なる波長でとどまる時間を変えることで動的に調整される。利得スペクトルを調整する別の方法は、異なる波長ごとに大多数のポンプパルスをラマンシフトファイバに使用することである。各波長ごとに相対的な数のパルスを変調することは、相対的な利得プロファイルを変更することを可能にする。

【００８１】より具体的に言うと、図１に示されたフェムト秒パルス光源は、高パワーのためにＹｂ増幅器で増幅される。これらのパルスは、フェムト秒パルス光源の動作点より短い波長で零分散点をもつファイバで、１４００－１５００ｎｍ領域にラマン自己周波数シフトされる。このファイバはホーリファイバでもよい。１４００－１５００ｎｍ領域にラマン自己周波数シフトをもつワットレベルのパワーを達成するためには、光源の最適繰り返し周期が１Ｇｈｚ以上の高周波数であるべきである。利得スペクトル拡張と自動利得制御は、異なる量のラマンシフトを得るために、大多数のポンプ波長を使用することで、ポンプ波長を同調することで、あるいは、パルス列の個々のパルスのパルス振幅を変調することで、得られる。

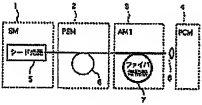
【図面の簡単な説明】

【図１】本発明に関する高ピーク、高平均パワー、超短レーザパルス発生用のモジュール化したコンパクトな波長可変システムの図である。

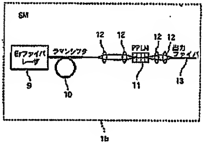
【図２】本発明に使用するためのシードモジュール（ＳＭ）の第一実施例の図である。

【図３】本発明の第一実施例に関する与えられた入力パワーで出力される平均周波数逓倍パワーと波長の関係を示すグラフである。
【図４】本発明で使用するためのパルス圧縮器モジュール（ＰＣＭ）の第一実施例の図である。
【図５】本発明で使用するためのパルス拡張器モジュール（ＰＳＭ）の第一実施例の図である。
【図６】本発明で使用するためのシードモジュール（ＳＭ）の第二実施例の図である。
【図７】本発明で使用するためのシードモジュール（ＳＭ）の第三実施例の図である。
【図８】本発明で使用するためのシードモジュール（ＳＭ）の第四実施例の図である。
【図９】本発明で使用するためのシードモジュール（ＳＭ）の第五実施例の図である。
【図１０】ファイバ分配モジュール（ＦＤＭ）が、図１に示された本発明の実施例に付加された本発明の一実施＊＊例の図である。
【図１１】本発明で使用するためのファイバ分配モジュール（ＦＤＭ）の一実施例の図である。
【図１２】本発明で使用するためのパルス拡張器モジュール（ＰＳＭ）の第二実施例の図である。
【図１３】本発明で使用するためのパルス拡張器の第三実施例の図である。
【図１４】パルス採集素子と付加的増幅段が付加された本発明の一実施例の図である。
【図１５】パルス採集素子ような光変調器と組み合わせてファイバ増幅器が少なくとも一つの前方パスと一つの後方パスで動作する本発明の別の実施例の図である。
【図１６】光通信の面における本発明の別の実施例の図である。
【図１７】電気通信用波長可変ラマン増幅器の面における本システムの別の実施例の図である。

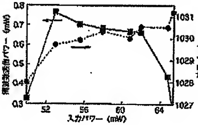
【図１】



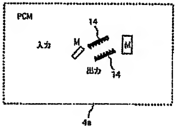
【図２】



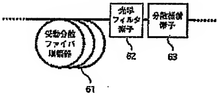
【図３】



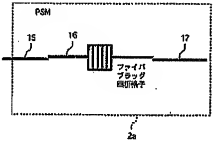
【図４】



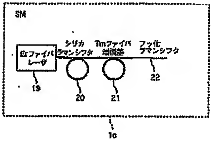
【図１６】



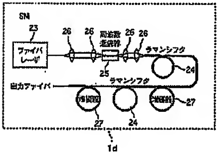
【図５】


PSM
15
16
17
ファイバ
ブラッグ
回折格子
2a

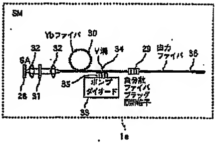
【図６】


SM
Erファイバ
レーザ
シリカ
ラマンシフタ
Tmファイバ
増幅器
フッ化
ラマンシフタ
19
20
21
22
1c

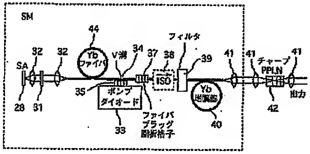
【図７】


SM
23
26
26
周波数
逓倍器
26
26
ファイバ
レーザ
ラマンシフタ
25
24
ラマンシフタ
出力ファイバ
27
27
24
1d

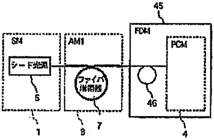
【図８】


SM
Ybファイバ
30
32
32
V溝
34
29
出力
ファイバ
36
SA
35
ポンプ
ダイオード
ファイバ
ブラッグ
回折格子
28
31
33
1e

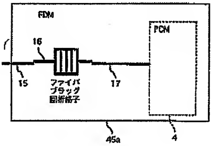
【図９】


SM
44
Yb
ファイバ
V溝
34
37
38
フィルタ
32
32
39
41
41
41
チャープ
PPLN
SA
ISO
35
ポンプ
ダイオード
Yb
増幅器
出力
28
31
33
ファイバ
ブラッグ
回折格子
40
42

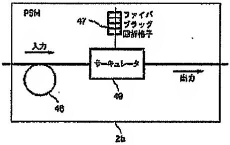
【図１０】



【図１１】



【図１２】



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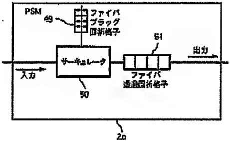
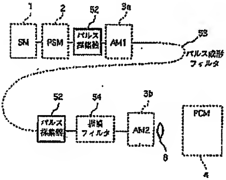
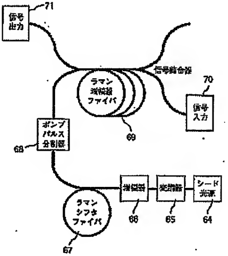


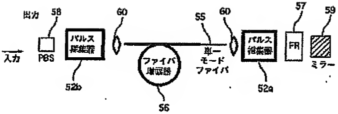
【図１４】



【図１７】



【図15】



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JP,2002-118315,A

CLAIMS

[Claim(s)]
[Claim 1]Laser system comprising:
Spectral band width of 0.3 nm or more.
A source of seed light which generates a pulse of the wavelength range with about 50 fs(es) and pulse width during 1 ns of 1-1.15 micrometers.
A fiber amplifier for a pulse of a wide bandwidth which outputs a pulse which inputted, amplified and amplified this pulse.
A pump laser for supplying laser energy to this fiber amplifier.

[Claim 2]Laser system characterized by comprising the following about claim 1.
Said source of seed light is fiber laser.
A nonlinear crystal which carries out frequency multiplying of the output of the Raman shifter which inputs an output of this fiber laser, and this Raman shifter.

[Claim 3]Said Raman shifter is a fiber of a silica base which carries out upper part conversion in a spectral range longer than 2000 nm, and further a radiation wavelength of said fiber laser said nonlinear crystal, Then, laser system about claim 2 which carries out lower part conversion of this wavelength by which upper part conversion was carried out in a 1000-1500-nm spectral range.
[Claim 4]Laser system about claim 2 whose wavelength alignment curve of a nonlinear crystal is below a center wavelength of an output of the Raman shifter.
[Claim 5]Laser system about claim 2 which has an amplification fiber with rare earth amplification ion selected since said Raman shifter generated a pulse of a non-amplification fiber or refractive index distribution, and the wavelength range of about 600-5000 nm.
[Claim 6]A silica Raman shift fiber which said source of seed light inputs an output of Er fiber laser and this Er fiber laser, and is outputted to said fiber amplifier, Laser system about claim 1 in which it has a fluoridation Raman shifter which inputs said amplified pulse, and said fiber amplifier is a Tm fiber amplifier.
[Claim 7]Laser system about claim 6 which has further a nonlinear crystal which inputs an output of a fluoridation Raman shift fiber so that frequency multiplying theory may be performed.
[Claim 8]Laser system characterized by comprising the following about claim 1.
Said source of seed light is Er fiber laser.
The Raman shifter which inputs a frequency multiplying output of a nonlinear crystal which inputs an output of this Er fiber so that frequency multiplying theory may be performed, and this nonlinear crystal.

[Claim 9]Laser system about claim 8 which said source of seed light is passive mode

locking fiber laser, and is a HORI fiber used in order for said Raman shift fiber to carry out the Raman shift of the frequency multiplying output of a nonlinear crystal to the wavelength range of about 750 to about 1050 nm.

[Claim 10]An amplification fiber with rare earth amplification ion which said source of seed light is passivity type mode locking fiber laser, and is different from a series of non-amplification fibers and different refractive index distribution, Laser system about claim 8 used in order to carry out the Raman shift of the frequency multiplying output of said nonlinear crystal to the wavelength range of about 750 to about 5000 nm.

[Claim 11]Laser system about claim 1 with which said source of seed light has passivity type mode locking fiber laser.

[Claim 12]Laser system about claim 11 in which said passivity type mode locking fiber laser is Yb fiber laser.

[Claim 13]Laser system about claim 11 in which said passivity type mode locking fiber laser is Nd fiber laser.

[Claim 14]Laser system about claim 11 in which said passivity type mode locking fiber laser is in many modes.

[Claim 15]Laser system about claim 14 in which said passivity type mode locking fiber laser is polarization maintenance.

[Claim 16]Laser system about claim 11 in which said passivity type mode locking fiber laser is polarization maintenance in a single mode.

[Claim 17]Laser system characterized by comprising the following about claim 1.

Said source of seed light is fiber laser.

A frequency shift fiber which inputs an output of this fiber laser and outputs an anti-stokes blue shift output.

[Claim 18]Laser system about claim 17 in which said fiber laser is Er, Er/Yb, or Tm fiber laser.

[Claim 19]Laser system about claim 1 which generates a pulse to which said source of seed light induces generation of a parabolic pulse with said fiber amplifier.

[Claim 20]Laser system about claim 19 which has further a coupler of said source of seed light, and said fiber amplifier which does, combines this source of seed light with this fiber amplifier, and has an optical fiber 1 km or less in length.

[Claim 21]Laser system about claim 1 which has further the optical supply fiber combined with an output of said fiber amplifier.

[Claim 22]Laser system about claim 21 chosen from a group which said optical supply fiber becomes from one number mode fiber connected to a HORI fiber, one number mode fiber and 1, or two single mode fibers.

[Claim 23]Laser system about claim 22 in which said source of seed light generates a pulse shorter than 100ps so that generation of a parabolic pulse may be induced with said fiber amplifier, and said fiber amplifier has a larger profit than 10 further.

[Claim 24]Laser system about claim 23 which has further a pulse dilator which outputs a pulse which extended this pulse dispersively when just right, and this extended it in response to a pulse from said source of seed light to said amplifier.

[Claim 25]Laser system about claim 24 which is the thing that it has a pulse compressor which compresses said amplified pulse in time, and this pulse compressor outputs a bandwidth marginal pulse about, as for distribution of this pulse compressor.
[Claim 26]Laser system characterized by comprising the following about claim 1.
Said source of seed light is Tm or Ho fiber laser.
A nonlinear crystal which inputs an output of this Tm or Ho fiber laser, and performs frequency multiplying theory.

[Claim 27]Laser system about claim 1 by which either Yb or Nd is added as for said fiber amplifier.
[Claim 28]Laser system about claim 1 which has further a pulse compressor for compressing an amplified pulse about in time to a bandwidth limit.
[Claim 29]Laser system about claim 1 which is the semiconductor laser in which direct modulation of said source of seed light was carried out.
[Claim 30]Laser system comprising:
A source of seed light which generates a pulse of the wavelength range with larger spectral band width, about 50 fs(es), and pulse width during 1 ns than 0.3 nm of 1-1.15 micrometers.
A pulse dilator which outputs a pulse which extended this pulse dispersively when just right, and this extended it in response to this pulse.
A clad pump fiber amplifier which has a bigger profit than 10, and amplifies and outputs it in response to a this extended pulse to a pulse of a wide bandwidth.
A pulse compressor which inputs a pulse [this] amplified and extended and compresses them in time to a bandwidth limit about.

[Claim 31]Laser system about claim 30 in which said pulse dilator has a fiber 1 km or less in length.
[Claim 32]Laser system about claim 30 in which said pulse dilator has a HORI fiber.
[Claim 33]Laser system about claim 30 in which said pulse dilator has one minority mode fiber.
[Claim 34]Laser system about claim 30 in which said pulse dilator has one minority mode fiber joined together with a single mode fiber of 1 or a large number.
[Claim 35]Laser system about claim 30 in which said pulse dilator has a single mode fiber 1 km or less in length.
[Claim 36]Laser system about claim 30 which has a fiber in which said pulse dilator has W-like refractive index profile.
[Claim 37]Laser system about claim 30 which has a fiber in which said pulse dilator has a multi-clad refractive index profile.
[Claim 38]Laser system characterized by comprising the following about claim 30.
One fiber in which said pulse dilator has the 3rd negative distribution.
A linearity chirp fiber diffraction grating with negative secondary distribution.

[Claim 39]Laser system characterized by comprising the following about claim 30.

Said pulse dilator is a linearity chirp fiber diffraction grating.
One or more fiber transmission gratings which have a value which can choose the 3rd high order distribution so that high order distribution may be compensated with a pulse compression means.

[Claim 40]Two or more additional fiber amplifiers connected between said pulse dilator and said pulse compressor, A fiber coupling machine which has an optical fiber 1 km or less in length, and combines said source of seed light with the first one of the additional amplifiers of this plurality, Laser system about claim 30 which has further two or more pulse collection means arranged whether they are before this fiber amplifier, after an additional fiber amplifier of this plurality or middle of one of these amplifiers, and ********.

[Claim 41]An amplifier which operates with a source of seed light which generates a pulse of the wavelength range with larger spectral band width characterized by comprising the following than 0.3 nm, about 50 fs(es), and pulse width during 1 ns of 1-1.15 micrometers, at least one front path, and one back path.
A clad pump fiber amplifier of a pulse sake of a wide bandwidth amplified and outputted in response to this pulse.
An optical modulator arranged between a pump laser for supplying laser energy to this fiber amplifier, one front path of this amplifier, and one back path.

[Claim 42]With two or more additional fiber amplifiers here at least one and two or more additional fiber amplifiers, . Operate with at least one front path and one back path. Laser system about claim 41 which has further a mode filter which penetrates preferentially dominant mode of an amplifier arranged after a path of the beginning of at least one aforementioned fiber amplifier which operates with at least one front path and one back path, and two or more additional fiber amplifiers.
[Claim 43]Laser system about claim 42 which has further one pulse collection machine arranged between at least one front path and one back path.
[Claim 44]A pulse light source which operates with a bigger output wavelength than 2 micrometers, comprising:
A source of seed light which outputs a pulse of short pulse width.
The first fiber Raman shifter which inputs this pulse and generates this output wavelength.

[Claim 45]A pulse light source about claim 44 which has further at least one additional fiber Raman shifter connected to said first fiber Raman shifter, and two or more fiber amplifiers connected by turns between these fiber Raman shifters.
[Claim 46]A pulse light source selected below at Raman-spectrum element-center wavelength of a seed pulse by which was been a pulse light source about claim 45 which has further the multiplying crystal connected to one of the last of said fiber Raman shifter, and the Raman shift of the wavelength alignment curve of this nonlinear crystal was carried out, and it was amplified.
[Claim 47]A lightwave pulse light source comprising:

Passivity type mode locking fiber laser.
Yb amplifier for amplifying an output of this fiber laser.

[Claim 48]A lightwave pulse light source about claim 47 in which said passivity type mode locking fiber laser has Yb fiber laser.
[Claim 49]An optical-communications subsystem comprising:
A pure normal dispersion fiber light amplifier connected to an optical fiber penetration line with a profit of 10dB/km or less, and a comprehensive profit of not less than 10 dB.
A dispersion compensation element arranged on this optical fiber penetration line, and a light filter arranged on this optical fiber penetration line.

[Claim 50]An optical-communications subsystem comprising:
A pure normal dispersion fiber light amplifier connected to an optical fiber penetration line with a profit of 3dB/km or less, and a comprehensive profit of not less than 20 dB.
A dispersion compensation element arranged at an end of an optical fiber penetration line.

[Claim 51]A quantity of self-phase modulation received by a lightwave pulse which is an optical-communications subsystem and penetrates this optical fiber penetration line characterized by comprising the following is an optical-communications subsystem with more normal-dispersion-optical-fiber element also to a twist at a **** dispersive device.
A normal-dispersion-optical-fiber element connected to an optical fiber penetration line.
A **** dispersive device too connected to an optical fiber penetration line.

[Claim 52]An optical-communications subsystem with which said negative dispersive devices were enumerated by claim 51 which has a chirp fiber diffraction grating.
[Claim 53]Quantity of self-phase modulation received by a lightwave pulse which is an optical-communications subsystem and penetrates an optical fiber penetration line characterized by comprising the following. It is an optical-communications subsystem with more HORI fiber also to a twist at a **** dispersive device.
Two or more HORI fibers with pure normal dispersion connected to an optical fiber penetration line.
Two or more **** dispersive devices too connected to an optical fiber penetration line.

[Claim 54]An optical-communications subsystem with which it is an optical-communications subsystem which inputs a pump train of impulses with length for 10 or less ns, also inputs a lightwave signal, amplifies, and has an optical Raman amplifier fiber to output, and this lightwave signal spreads this Raman amplifier fiber to a counter direction about a pump pulse.
[Claim 55]An optical-communications subsystem about claim 54 aligned by alignment operation in which said optical Raman amplifier is carried out by said pump pulse.
[Claim 56]An optical-communications subsystem characterized by comprising the following about claim 55.
A source of seed light which outputs a lightwave pulse.

A modulator which modulates this lightwave pulse.
The Raman shifter fiber which inputs a modulated this lightwave pulse.
A Raman amplifier which inputs an output of this Raman shifter fiber.

[Claim 57]An optical-communications subsystem about claim 56 including that said alignment operation modulates at least one of power of this seed pulse, wavelength, and the width before said seed pulse is poured into said Raman shifter fiber.
[Claim 58]Laser system about claim 9 which is a HORI fiber which changes on wavelength so that said Raman shift fiber may optimize said Raman shift in a meaning with distribution.
[Claim 59]Laser system with which this seed pulse is generated and this fiber amplifier is formed so that it may be laser system and a pulse made with this fiber amplifier may be parabolic, comprising:
A light source of a seed pulse.
A fiber amplifier which inputs and amplifies this seed pulse.

[Claim 60]Laser system which is laser system and generates a pulse to which the source of seed light induces parabolic pulse form Shigeru with this fiber amplifier, comprising:
A light source of a seed pulse.
A fiber amplifier which inputs this seed pulse, amplifies and outputs an amplified pulse.

[Claim 61]Laser system with which this seed pulse is generated and this fiber amplifier is formed so that it may be laser system and a pulse made with this fiber amplifier may be parabolic, comprising:
A light source of a seed pulse.
A fiber amplifier which outputs a pulse which inputted, amplified and amplified this seed pulse.

[Claim 62]An optical-communications subsystem comprising:
A light source of a lightwave pulse of different wavelength.
A means to correct dynamically a degree of a Raman shift experienced in each of this different **** wavelength.

[Claim 63]Improvement which has at least one Raman shifter in an optical fiber communications system of a type which has a fiber light carrier circuit which conveys a lightwave signal of different wavelength, and at least one fiber laser amplifier which imposes a profit which is different to a signal of this different **** wavelength.
[Claim 64]A source of seed light characterized by comprising the following for laser system.
Fiber laser which generates a pulse output.
A nonlinear crystal which carries out frequency multiplying of the output of the Raman shifter which inputs a pulse output of this fiber laser, and this Raman shifter.

[Claim 65]A source of seed light characterized by comprising the following for which claim 64 was asked.
A heavy current nature optical material in which said nonlinear crystal was chosen from a group which consists of PPLN, PP lithium tantalate, PP $MgO{:}LiNbO_3$, and PP KTP and which carried out the pole periodically.
A crystal in which a KTP isomorph carried out the pole periodically.

[Claim 66]A source of seed light which is a source of seed light for which claim 65 was asked, and is selected in order that the section of said nonlinear crystal may control the pulse length of a pulse output of this source of seed light.
[Claim 67]A source of seed light which is controlled by an output wavelength of said nonlinear crystal controlling temperature of this nonlinear crystal and for which claim 65 was asked.
[Claim 68]A distribution system for fiber laser systems characterized by comprising the following which operates in parabolic pulse organization.
A supply fiber.
W-fiber for compensating the 3rd distribution of a diffraction grating type pulse compressor and this pulse compressor.

[Claim 69]Dispersion compensation arrangement for fiber laser amplification systems characterized by comprising the following which operates in parabolic pulse organization.
A pulse dilator which is arranged in front of an amplifier stage of this system, and contains at least one negative 3rd distribution generator child.
A pulse compressor arranged after this amplifier stage in order to have the 3rd positive distribution that cancels distribution introduced by this dilator and to compensate secondary distribution.

[Claim 70]Dispersion compensation arrangement for fiber laser amplification systems characterized by comprising the following which operates in parabolic pulse organization.
A pulse dilator containing at least one Bragg fiber diffraction grating and a fiber transmission grating for being arranged in front of an amplifier stage of this system, and generating at least one positive secondary distribution generator child and the 3rd distribution [4th].
A pulse compressor arranged after this amplifier stage in order to have the 3rd positive distribution that cancels distribution introduced by this dilator and to compensate secondary distribution.

[Claim 71]A wavelength variable Raman amplifier comprising:
A light source of a femtosecond organization seed pulse.
A Raman shift fiber which carries out a wavelength shift in response to this seed pulse in order to form a pump pulse.
A Raman amplifier fiber into which this pump pulse and two or more signal wave long pulses spread to a counter direction were poured.

A means to modulate at least one of power of this seed pulse, wavelength, and the width in order to carry out wavelength alignment of this pump pulse and to align a center wavelength of Raman gain of this Raman amplifier.

[Claim 72]An amplifier by which wavelength alignment is carried out with a time period below signal pulse crossing time of this Raman amplifier so that it may be the amplifier for which claim 71 was asked and said pump pulse may double said signal pulse with an effective correction Raman gain spectrum.

[Claim 73]Wavelength variable laser system comprising:

Fiber laser which generates a pulse output with pulse width for 1 or less nanosecond.

distribution -- a little -- or -- a HORI fiber which changes on wavelength so that wavelength alignment may be optimized.

[Claim 74]Are wavelength variable laser system characterized by comprising the following, are in wavelength tuning range, and this HORI fiber, Wavelength variable laser system in which negative secondary distribution is shown, it has secondary distribution zero to an input pulse light source on wavelength of less than 300 nm, and an absolute value equal to an absolute value of the 3rd material dispersion of silica or the 3rd distribution not more than it is shown.

Fiber laser which generates a pulse output.

distribution -- a little -- or -- a HORI fiber which changes on wavelength so that wavelength alignment may be optimized.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Background of the Invention]1. The wavelength selection of the invention of ****** of an invention is possible, it is compact, it is a module type and this super-short laser pulse light source is a fundamental component [in / about an efficient high-power super-short laser pulse light source / industrial use of ultra high-speed laser technique].

[0002]2. It is recognized as the description fiber laser of a pertinent art having given the effective medium for ultrashort pulse generating for a long time until now. However, such [until now] a system, . Mainly have the option restricted to wavelength variable nature, and the minimum pulse width that can be attained has a limit. The Bragg diffraction (chirp was carried out) lattice which wavelength shifted dynamically. The pulse from which the used instantaneous frequency changes. (Pulse which carried out the chirp). Were based on amplification. (A. Galvanauskas and M.E. Fermann,'Optical Pulse Amplification using Chirped Bragg Gratings,'United States Patent,No.5,499,) 134) . The Bragg diffraction lattice which carried out the chirp has developed into the device which can be obtained very widely, and in a Bragg diffraction lattice a chirp, Linearity or in order to compensate distribution of the arbitrary order within a chirp pulse amplification system, Nonlinear, . Skill is also designed. (A.Galvanauskas et al.,'Hybrid Short-Pulse Amplifiers with Phase-

MismatchCompensated Pulse Stretchers and Compressors',U.S.) Patent No.5,847,863 and this chirp pulse amplification system are important for generating of pulse ** made shortest for a bandwidth restriction pulse, i.e., the pulse bandwidth of the given spectrum.
[0003]In order to maximize the power of an optical fiber, and the limit of energy, using chirp pulse amplification, Although it is clearly desirable, the demand (the Bragg diffraction lattice needs to operate by reflection rather from a penetration, in order to give the possible highest distribution) of system integration directs use of such a standard chirp pulse amplification system simultaneously. As a substitute of chirp pulse amplification, . The high-power pulse amplification in the multimode fiber amplifier was proposed. (M. E. Fermann and D. Harter,'Single-mode Amplifiers and Compressors Based on Multi-mode Optical Fibers',UnitedStates) Patent, No.5,818,630. What [soliton Raman compression with a fiber amplifier is used for as a substitute of chirp pulse amplification], Or generally, The pulse compression in the inside of a nonlinear fiber amplifier. . Using it was proposed. (M.E.Fermann, A.Galvanauskas and D.Harter,'Apparatus and Method for the Generationof High-power Femtosecond Pulses from a) Fiber Amplifier', United States Patent, No.5,880,877.
[0004]Clearly, use of a multimode fiber is combined with chirp pulse amplification and soliton Raman compression in order to improve the performance of such a system further. However, the pulse form-like controlling method for optimizing the whole system performance further till today was not described at all. Similarly, using a self--phase modulation for the dilator portion of such a chirp pulse amplification system was not proposed.
[0005]What a fiber dispersion delay line is used for jointly with a bulk optical compressor as a compromise of miniaturization of a system, and high-energy-izing, It is advantageous and at least, Partial integration of a high-energy fiber laser system. . Bring. (M.E.Fermann A.Galvanauskas and D.Harter:'All fiber souce of 100 nJ sub-picosecond pulse',Appl.Phys.Lett.,vol.64,1994,pp.) 1315-1317. However, in order to repress a pulse to near the bandwidth limit till today, the effective method of controlling higher order 3rd distribution [4th] in the combination of a dilator and a compressor was not developed at all.
[0006]By using the single mode erbium amplifier of a high-profit normal dispersion (non soliton is made to maintain) silica base as a substitute of chirp pulse amplification combining a bulk prism compressor, Effective pulse compression. If obtained. It says. Before **. Proposed (K.Tamura and M.Nakazawa,'Pulse Compression by Nonlinear Pulse Evolution with Reduced Optical Wave Breaking in Erbium- Doped Fiber Amplifiers, 'Opt.Lett., Vol.21, p.68 (1996). However, the thing for which this art is used jointly with the erbium amplifier of a silica base, Because it is a problem, it is because the demand for normal dispersion restricts fiber core size to about 5 microns, or negative material dispersion governs positive waveguide dispersion and the whole is made into negative fiber dispersion. Similarly, the multimode fiber of a silica base had negative distribution on erbium amplifier wavelength, and has barred using them for effective pulse compression. Thus, the core size to which the normal dispersion erbium amplifier was limited decreases greatly the pulse energy which can be attained.

[0007]The method of performing an additional spectrum expansion and pulse amplification after one erbium amplifier was not shown by Tamura and others. The method of making the performance of a prism pulse compressor similarly optimize, in order to compensate distribution of an erbium amplifier was not taught by Tamura and others.
[0008]Using a non-amplifying optical fiber jointly with a bulk diffraction grating compressor as another substitute of chirp pulse amplification was proposed (D. Grischkowsky et al.and J.Kafka etal., U.S.Patent No.4,750,809). However, since there is no profit in such a system, high pulse energy must be combined with a nonlinear optical element in order to obtain high-output power, and the peak power characteristic of a system is reduced. It did not argue about the method of compensating higher order distribution with such optical arrangement, but it has restricted the implementability of this approach greatly. The spectrum breadth with a linearity chirp is obtained without controlling the shape of a pulse form in the input to such a system only with the input control power limited dramatically. Kafka and others did not argue about control of input pulse shape. Similarly, in order to acquire the shortest possible pulse jointly with a bulk diffraction grating compressor, the secondary distributed control [3rd] in such a nonlinear optical element were needed, but Kafka and others did not argue about this, either.
[0009]The chromatism compensation in the light wave signal (low power) which uses chromatism into another (distributed-compensation) waveguide device, In order to optimize the performance of a telecommunication system. It was introduced (C.D.Poole,'Apparatus of compensating chromatic dispersion in optical fibers,'US Patent No.5,185,827).). However, in the case of a high-power pulse light source, the self--phase modulation introduced by the distributed-compensation waveguide device bars those effective use. In order that the system about which Pool argued may absorb higher mode selectively in a distributed-compensation waveguide device, in order [or] to amplify dominant mode selectively in a distributed-compensation waveguide device -- a mode converter -- and -- or jointly with a rare earth added fiber, it only operates. The method of compensating distribution of the high-power lightwave pulse under existence of a self--phase modulation was not taught at all, and the method of carrying out a distributed-compensation waveguide without a mode converter was not proposed at all.
[0010]Instead of using a mode converter and higher mode, [******] The refractive index profile of W-style. . The fiber which it has is known. (B.J.Ainslie and C.R.Day, 'A review of single-mode fibers with modified dispersion characteristics';J.Lightwave Techn.,vol.) LT-4, No.8, pp.967-979-1988. However, it did not argue about the use of such a fiber design to a high-power fiber chirp pulse amplification system.
[0011]In order to make efficiency of an ultra high-speed fiber amplifier into the maximum, Use of Yb fiber amplifier was proposed (D. "Broad-bandwidth pulse amplification to the 10microj level). [T.Walton, J.Nees and G.Mourou,] in an ytterbium-doped germanosilicate fiber, "Opt.Lett., vol.21, no.14, and pp.1061 (1996) -- however, Although the research by Walton and others adopted argon laser-pumps Ti:sapphire laser as excitation of Yb addition fiber, it not only adopts mode locking Ti:sapphire laser as a light source of a signal pulse, but, Efficiency is [this] bad and clearly incompatible with a

compact apparatus dramatically. Although it was not proposed at all, i.e., the 100fs pulse from Ti:sapphire laser was combined with Yb amplifier through a single mode fiber distribution delay line 1.6 km in length, the method of controlling the phase of a lightwave pulse by an amplification process, A big phase distortion by the high order distribution which restricts greatly that this delay line applies a system to ultra high-speed amplification is started. In order to induce a quality high-power parabolic pulse in Yb amplifier, the seed pulse of the range of 200-400fs is more preferred to Yb amplifier of the length which is 2 or 3 m than to it. Use of the single mode Yb addition fiber amplifier by Walton and others restricts the energy of Yb amplifier, and the limit of power still more greatly. Although use of the multi-mode Yb addition fiber was proposed by U.S. application No.09/317,221 by which the contents were incorporated here as a reference, the small ultrashort pulse light source which is compatible with Yb amplifier remained, while it had been unclear.
[0012]The Hiroyoshi strange pulse Yb-fiber laser included in an active light modulation mechanism, . Were described recently. (J.Porta et al.,'Environmentally stable picosecond ytterbium fiber laser with a broad tuning range',Opt.Lett.,vol.23,pp.615) -617 (1998). Although this fiber laser has provided the tuning range in the profit bandwidth of Yb about, applying that laser to ultra high-speed optics is restricted by the comparatively long pulse generated by that laser. The bandwidth of the pulse which the active mode locked laser generally generated the pulse longer than a passive mode locked laser, and was generated in the case of this actual condition has the minimum pulse width of 5ps, and is [whether it is small and] 0.25 nm.
[0013]The extensive wavelength variable fiber laser light source which used the Raman shift jointly with the frequency conversion in the inside of a nonlinear crystal was described recently. (M.E.Fermann et al.,US Patent No.5,880,877 and N.Nishizawa and T.Goto,"Simultaneous Generation of Wavelength Tunable Two-) Colored Femtosecond Soliton Pulses Using Optical Fibers, "PhotonicsTechn.Lett., vol.11, no.4, pp421-423 reference. The eternal Raman shifter is proposed spatially fundamentally and, as a result, the wavelength variable range is restricted to 300 to 400 nm (refer to Nishizawa et al.). The application which a Raman shift continues, and no methods of making the minimum the noise of an advanced nonlinear system based on the nonlinear frequency conversion in a nonlinear optical crystal are known. The system described by Nishizawa and others was connected with the comparatively complicated low power polarization control erbium fiber oscillator amplified with the additional polarization control erbium fiber amplifier for seeding the Raman shifter. No methods of making possible the Raman shift of the frequency multiplying output from Er fiber laser are described.
[0014]The Raman shifter which is a pulse from a high-power fiber oscillator, or was directly seeded by the pulse by which frequency conversion was carried out from the high-power fiber oscillator is clearly preferred. Such a fiber oscillator, These days multimode optical fiber. . Were used and described. (M.E.Fermann,'Technique for mode-locking of multi-mode fibers and the construction of compact high-power fiber laser pulse) sources', U.S.serial number 09/199,728. However, the method of changing the frequency of an oscillator which used the Raman shift after that is not proved till today.

[0015]
[Summary of the Invention]Therefore, the purpose of this invention is to be easy to modularize and to provide small size, an extensive wavelength variable, a high peak, high average power, and low noise ultra high-speed fiber amplification laser system.
[0016]1) The source of short pulse seed light, 2 extensive bandwidth fiber amplifier, 3 distribution short pulse expansion element, 4) a distributed pulse compression element, 5 nonlinear frequency conversion element, the optic for 6 fiber distribution, and ** -- it is another purpose of an invention to ensure modularization of a system by using various easily exchangeable optical systems [like]. The proposed arbitrary modules may be constituted by the exchangeable low rank set of an optical system.
[0017]It is another purpose of an invention that the distributed delay line integrated highly and the effective fiber amplifier by which the pump was carried out directly or indirectly by the diode laser ensure the miniaturization of a system by using it. The high-peak-power characteristic of a fiber amplifier is using the optimized shape of a pulse form of parabolic or others, and is expanded greatly. Jointly with self-phase modulation, a parabolic pulse enables generating of a large bandwidth and a high-peak-power pulse, and distributed pulse extension controlled well. The high gain which operates on the wavelength which is positive has the single material dispersion of a fiber, or a high-power parabolic pulse is generated with a multimode fiber amplifier.
[0018]or [that a parabolic pulse is distributed along with considerable fiber length also under existence of self-phase modulation or general Kerr effect type optical nonlinearity] -- or it is spread and a pulse chirp [enough linearity] is caused. At the end of such fiber distribution or a fiber propagation line, a pulse is about compressed to a bandwidth limit.
[0019]The high energy characteristic of a fiber amplifier is greatly expanded by using chirp pulse amplification jointly with a parabolic pulse or other shape of optimal pulse form, and the shape of the pulse form makes possible much [without degradation of pulse quality] self-phase modulation. The chirp pulse amplification system integrated more by the altitude, It is made from using the nonlinear crystal (the pole was carried out) which connects a bulk optical pulse compressor (or low nonlinearity Bragg diffraction lattice) or pulse compression to frequency conversion and which arranged the orientation of the dye molecule periodically, without spoiling the high energy characteristic of an optical fiber.
[0020]Distribution with a fiber pulse dilator and a bulk optical compressor is incorporating a fiber pulse dilator with the secondary distribution [3rd / 4th] that can be adjusted, and suits the phase of the order of 1/4. The high order distribution which can be adjusted is obtained using a high numerical aperture single mode fiber with the refractive index distribution which is itself or was optimized by using a standard stair-like refractive-index-distribution (step index) high numerical aperture fiber jointly with a linearity chirp fiber diffraction grating. Or high order distribution is using a nonlinear chirp fiber diffraction grating or a linearity chirp fiber diffraction grating jointly with a transmission type fiber diffraction grating, using the dispersion property of the higher mode in the number mode fiber of a high numerical aperture, and is controlled. The 4th distribution that can be adjusted is using the fiber which controls the chirp of a fiber Bragg diffraction grating and a transmission type fiber diffraction grating, and has the secondary distribution [3rd / 4th]

of a different rate, and is obtained. Similarly, high order distribution is obtained by using the nonlinear crystal which carried out the pole periodically.

[0021]A fiber amplifier is seeded with the short-pulse-laser light source which carried out the form of the short pulse fiber light source preferably. In the case of Yb fiber amplifier, the frequency multiplying short pulse Er fiber laser light source which carried out the Raman shift is mounted as a source of extensive wavelength variable seed light. In order to make the noise of the frequency conversion from 1.5 micrometers to 1.0 micrometer into the minimum, the self--restriction Raman shift of Er fiber laser pulse light source is used. Or the noise of a nonlinear frequency conversion process is minimized by carrying out self--limit frequency multiplying. The center wavelength of the alignment curve of a multiplying crystal is shorter than the center wavelength of the Raman shift pulse.

[0022]The process of a Raman shift and frequency multiplying can also be made reverse. there, frequency multiplying of the Er fiber laser is carried out first, after that, it is the optimized fiber which is alike and receives and gives soliton maintenance distribution, and a Raman shift is carried out to the wavelength of around 800 nm, and the higher wavelength for building the 1-micrometer source of seed light for wavelength organization.

[0023]Mode locking Yb fiber laser is used as a substitute of the source of low-complicated seed light for Yb amplifiers. Fiber laser is designed so that the pulse which carried out the chirp strongly may be made, and in order that a light filter may select the seed pulse close to the bandwidth limit for Yb amplifiers, it is combined.

[0024]Since a parabolic pulse is transmitted along with sufficient fiber length, the pulse is used also for a fiber optics communications system. In this system, the parabolic pulse generated with the outside pulse light source is transmitted. Or a parabolic pulse is generated also a transmission process. In the latter case, a harmful operation of the optical nonlinearity in transmission systems is generally minimized by mounting a long distribution pattern and normal dispersion light amplifier. Such an amplifier has a profit of a length of at least 10 km, and 10dB/km or less. All the profits per amplifier should exceed 10 dB, in order to utilize the start of the parabolic pulse forming for minimization of a harmful operation of optical nonlinearity. Chirp compensation of a transmission line is using a chirp fiber Bragg diffraction grating also for the end of the transmission line as meeting a fiber transmission line, and is usually carried out. An optical bandwidth filter is further mounted for bandwidth control of the transmitted pulse.

[0025]The wavelength variable pulse light source based on the Raman shift of the short pulse in an optical fiber is useful at many application, for example, a spectroscopic analysis. However, a very attractive device is made from applying a Raman shift to manufacture of the wavelength variable fiber Raman amplifier for telecommunication systems. In this wavelength variable system, the pump pulse which carried out the Raman shift gives Raman gain for the variable wavelength range, and is shifted to red about a pump pulse. The shape of the Raman gain spectrum is modulating the pump pulse which carried out the Raman shift, and is controlled. [0026]

[Detailed explanation of the submitted example] The system chart where the invention was generalized is shown in drawing 1. The pulse generated in the source 1 (seed module; SM) of laser seed light is combined with the pulse extension module 2 (PSM), and, as for a

pulse, time is extended dispersively there. The extended pulse is combined with the dominant mode of the Yb fiber amplifier 3 (an amplifier module, AM1) by which the clad pump was carried out, and a pulse is amplified at least 10 times there. Finally, it is combined with the pulse compressor module 4 (PCM), and a pulse is mostly compressed in time to near the bandwidth limit there.
[0027]the example shown in drawing 1 is a module type -- **, four subsystem;SM1, PSM2, AM13, PCM4, ** and others As indicated in the another example, of course, a subsystem is used for different shape, even when it is individual.
[0028]Hereafter, an argument relates to a SM-PSM-AM1-PCM system. SM1 has a femtosecond pulse light source (source 5 of seed light) preferably. PSM has the one fiber 6 preferably and combination between SM and PSM is preferably performed by weld. The output of PSM is preferably poured into the dominant mode of the Yb amplifier 7 inside the AM1 module 3. combination -- the bulk optical imaging system between weld, a fiber coupling machine, or PSM2 and the fiber amplifier 7 -- it is carried out by coming out. All the fibers are preferred and a polarization maintenance type is chosen. PCM4 has preferably a distributed delay line formed by one or two bulk optical diffraction gratings for the reason for a miniaturization. Or many bulk optical prisms and Bragg diffraction lattices are used for PCM4. Combination to PCM4 is performed by the bulk optical lens system as described by drawing 1 with the single lens 8. In the case of PCM containing a fiber Bragg diffraction grating, a fiber pigtail is used for the combination to PCM.
[0029]As an example of the source of femtosecond laser seed light, Raman-shift-frequency multiplying Er fiber laser is shown in SM1b of drawing 2. The femtosecond laser 9 is a commercial high energy soliton light source (IMRA America, Inc., Femtolite B-60TM) which supplies a 200fs pulse on the wavelength of 1.57 micrometers and in which it supplies the pulse energy of 1nJ with the repeating cycle of 50 Hz.
[0030]For the optimal Raman shift to a 1.5 to 2.1-micrometer wavelength area, reducing core ** (it taper-ized) is performed to the longitudinal direction of the polarization maintenance Raman shift fiber 10. Reduction of core ** is needed in order to maintain the secondary distribution by the Raman shifter to near the zero (however, negative) in the full wave length range up to 1.5 to 2.1 micrometers. By keeping it small, the absolute value of secondary distribution is minimized by the pulse width within the Raman shifter, and it this, Maximization of the Raman frequency shift is brought about (J. P.Gordon, "Theory ofthe Soliton Self-frequency Shift, "Opt.Lett., 11,662 (1986)). Without taper-izing, generally the Raman frequency shift is restricted to around 2.00 micrometers, and these 2.00 micrometers are not in agreement with the profit bandwidth of Yb fiber amplifier after frequency multiplying.
[0031]In this special example, the two-step Raman shifter 10 which consists of a silica 'Raman' fiber (it is a single mode at 1.56 micrometers) of length (30m and 3m) which has core ** (6 micrometers and 4 micrometers), respectively is mounted. When the beginning of the infrared-absorption end of silica is 2.0 micrometers, it is advantageous to increase the taper-ized rate to the terminal direction of the Raman shifter 10. In the present example, not less than 25% of the conversion efficiency from 1.57 micrometers to 2.10 micrometers is acquired. Better conversion efficiency is acquired by mounting a single taper-ized fiber

with core ** which changes smoothly more using many fibers with core ** which changes smoothly.

[0032]Frequency conversion to the 1.05-micrometer field of the pulse which carried out the Raman shift is performed by the LiNbO3 (PPLN) crystal 11 of one have the polling cycles selected suitably which carried out the pole periodically. (Although it is all these specifications) PP lithium tantalate which carried out the pole periodically [a desirable material for frequency conversion is required like PPLN and / others], It should be understood that the crystal in which a heavy current nature optical material like PP $MgO:LiNbO_3$ and PP KTP or the KTP isomorph carried out the pole periodically is also used advantageously. The combination with PPLN crystal 11, It is carried out to drawing 2 using the lens system indicated to be the lens 12. The output of PPLN crystal 11 is combined with the output fiber 13 with the lens 12. In the case of the 2.1-micrometer frequency multiplying which brings about the pulse energy of 40 or more pJ in a 1-micrometer wavelength area, the conversion efficiency of 16% is acquired. The spectral band width of the pulse by which frequency conversion was carried out is selected by suitable selection of the length of PPLN crystal 11, for example, a PPLM crystal 13 mm in length generates the bandwidth of 2 nm in the 1.05-micrometer field corresponding to the pulse width of about 800 fs(es). The generated pulse width is proportional to the length of a PPLN crystal about. That is, the pulse with the pulse width of 400fs by which frequency conversion was carried out needs PPLN 6.5 mm in length. The pulse width of 100fs to which the pulse which continued and carried out the Raman shift until the pulse width to which frequency conversion of this pulse width reduction was carried out reached about 100 fs(es) was restricted restricts reduction of the further pulse width.

[0033]When the pulse width by which frequency conversion was carried out is longer than the pulse width of the pulse which carried out the Raman shift enough, the wide bandwidth of the Raman pulse is utilized in order to enable wavelength alignment of a pulse by which frequency conversion was carried out. That is, effective frequency conversion is obtained on frequency for the pulse ranges from 2 (omega1-deltaomega) to 2 (omega1+deltaomega). Here, 2deltaomega is the spectral band width in the half of the maximum of the spectrum of the pulse which carried out the Raman shift. Continious wave length alignment here is simply performed by adjusting the temperature of the frequency conversion crystal 11.

[0034]The Raman shifter and the noise by which combination ** of the PPLN crystal was amplified are minimized as follows. The self-restriction Raman shift of Er fiber laser pulse light source is used by extending a Raman shift to the larger one in the optical fiber of a silica base than 2 micrometers. In the case of not less than 2-micrometer wavelength, the infrared-absorption end of silica begins to decrease a pulse greatly, and restriction of a Raman shift and reduction of amplification change are brought about. That is, the pulse energy in 1.5 micrometers which increased is useful to shift to bigger absorption than a bigger Raman shift and a 2-micrometer wavelength area, and this increase follows and stabilizes the pulse amplitude in this field which carried out the Raman shift.

[0035]Or it is shorter than the center wavelength of the pulse which the noise of the nonlinear frequency conversion process was minimized by performing self-limit frequency multiplying, and carried out the Raman shift of the center wavelength of the alignment

curve of a multiplying crystal in that case. Again, the pulse amplitude which the pulse energy in a 1.5-micrometer field which increased caused the frequency conversion efficiency which moved to the bigger Raman shift and decreased, therefore carried out frequency multiplying is stabilized. Therefore, the fixed power by which frequency conversion was carried out is obtained to a big change of input control power.

[0036]This is shown in drawing 3, and is and the average power in a 1-micrometer wavelength area by which frequency conversion was carried out is shown as a function of the average input control power in 1.56 micrometers here. Self--limit frequency multiplying ensures that the frequency shift in a 1-micrometer wavelength area is not dependent on the average input control power in the wavelength area which is 1.56 micrometers, as shown also in drawing 3.

[0037]There are some things which can be chosen in PSM2. In order to acquire the pulse near a bandwidth limit from a system when one fiber (extended fiber) is used as PSM as shown in drawing 1, a suitable distributed delay line is used for PCM4. However, if the distributed delay line of PCM4 comprises the diffraction grating 14 of bulk as shown in drawing 4, a remarkable problem will arise. the secondary ratio [3rd] -- the secondary ratio [3rd] in the typical stair-like refractive-index-distribution optical fiber in which the |3/2| next distribution operates in a 1-micrometer wavelength area -- compared with |3/2| next distribution, it is 1 to 30 times larger in a diffraction grating type distribution delay line. In the case of a standard stair-like refractive-index-distribution fiber with the low numerical aperture which operates in a 1-micrometer wavelength area, the numerals of the 3rd distribution with a fiber are the same as that in a diffraction grating type distribution delay line. Thus, jointly with a diffraction grating type dilator, a fiber dilator does not become a reserve means of the 3rd high order distribution by system compensation-sake.

[0038]In order to perform pulse extension of 10 or more times, control of the 3rd high order distribution becomes important for the optimal pulse compression of PCM4. The fiber in which the extended fiber 6 of PSM2 has W-like multi-clad refractive index distribution in order to overthrow this problem, that is, 'W-fiber' (B. J.Ainslie.) et al. Or a HORI fiber. It is replaced with (T.M.Monroe etal.,'Holey Optical Fibers'An Efficient Modal Model,J.Lightw.Techn.,vol.17,no.6,pp.1093-1102). Both W-fiber and a HORI fiber permit the secondary adjustment possible value [3rd] of high order distribution. With possible small core size, the value of the 3rd bigger distribution than the value in a standard single mode fiber is obtained with W and a HORI fiber. Mounting is similar to being shown in drawing 1.

It is not displayed independently.

I hear that the PSM operates with a transmission type purely, and the predominance of such a system has it. That is, PSM avoids use of the distributed Bragg diffraction lattice which operates with a reflection type, and is connected to the outside in a system for a different system configuration.

[0039]PSM2 [another] with the secondary adjustment possible value [3rd] of the 4th distribution is shown in drawing 5. As for PSM20a, the usual stair-like refractive-index-distribution optical fiber is based on positive, zero, or the principle that it undertakes, and it shifts and that 3rd distribution can be made. The value of the 3rd highest distribution is

made from the thing in a fiber for which the higher mode of the beginning of a fiber and LP gas_{11} mode near the cut-off are used. By drawing 5, the 4th distribution [3rd] of PSM20a are using the three sections 15, 16, and 17 of a pulse extension fiber, and is adjusted. The first extended fiber 15 is one fiber with the 3rd suitable distribution [4th] of zero. It is connected to the 2nd extended fiber 16, and as well as all the chirp pulse amplification systems, the first extended fiber 15 is selected in order to compensate the 3rd distribution of a diffraction grating compressor. In order to secure the predominance of the 3rd distribution in LP gas_{11} mode, centering on as mutual a fiber as the 2nd extended fiber 16, the first extended fiber 15 has offset, and is connected, and the main excitation in LP gas_{11} mode in the 2nd extended fiber 16 is brought about. In order to maximize the value of the 3rd distribution with the 2nd extended fiber 16, a fiber with high numerical aperture NA>0.20 is desirable. In order to make LP gas_{11} mode spread after the dominant mode of the 3rd extended fiber 17, similar connection technology is used at the end of the 2nd extended fiber 16. The 4th distribution of all the amplifiers and a compressor is minimized by suitable selection of a fiber. The 3rd extended fiber 17 has the distribution which can be disregarded, and is made short.

[0040]By the loss beyond 50% or it which is received by performing the power propagation to LP gas_{01} mode from LP gas_{11} mode without use of an optical mode converter and which is not avoided, the propagation loss of all the fiber dilator assemblies is at least 25%. The energy of the emainder in LP gas_{01} mode of the 2nd extended fiber is reflected by the reflection type fiber grating 18 which can be chosen, as shown in drawing 5. It permits eliminating one mode selectively to another side for the pulse which changes while a diffraction grating resonance wavelength is ten to 40 nm between the two modes, and has the spectral band width [it is ten to 40 nm] of a between according to a difference with a big effective refractive index between dominant mode and the following higher mode.

[0041]The energy loss of a fiber dilator assembly is aligning the 3rd extended fiber 17 with Yb amplifier, and is made small. This mounting is not shown independently.

[0042]When the 4th distribution is not large, the first extended fiber 15 is removed. The 4th distribution will also be compensated with using the first extended fiber with the 3rd distribution that is not zero if the 4th distribution even differs from the 3rd order between the beginning and the 2nd extended fiber.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1]It is a figure of the high peak about this invention, high average power, and the modularized compact wavelength variable system for super-short laser pulse generating.

[Drawing 2]It is a figure of the first example of the seed module (SM) for using it for this invention.

[Drawing 3]It is a graph which shows the relation of the average-frequency multiplying power and wavelength which are outputted with the given input control power about the first example of this invention.

[Drawing 4]It is a figure of the first example of the pulse compressor module (PCM) for using it by this invention.
[Drawing 5]It is a figure of the first example of the pulse dilator module (PSM) for using it by this invention.
[Drawing 6]It is a figure of the second example of the seed module (SM) for using it by this invention.
[Drawing 7]It is a figure of the third example of the seed module (SM) for using it by this invention.
[Drawing 8]It is a figure of the fourth example of the seed module (SM) for using it by this invention.
[Drawing 9]It is a figure of the fifth example of the seed module (SM) for using it by this invention.
[Drawing 10]A fiber distribution module (FDM) is a figure of one example of this invention added to the example of this invention shown in drawing 1.
[Drawing 11]It is a figure of one example of the fiber distribution module (FDM) for using it by this invention.
[Drawing 12]It is a figure of the second example of the pulse dilator module (PSM) for using it by this invention.
[Drawing 13]It is a figure of the third example of the pulse dilator for using it by this invention.
[Drawing 14]It is the figure of one example of this invention with which the pulse collection element and the additional amplification stage were added.
[Drawing 15]a pulse collection element -- it is a figure of another example of this invention in which the fiber amplifier operates with at least one front path and one back path combining an optical modulator [like].
[Drawing 16]It is a figure of another example of this invention in the field of optical communications.
[Drawing 17]It is a figure of another example of this system in the field of the wavelength variable Raman amplifier for telecommunication.

CORRECTION OR AMENDMENT

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[Amendment 1]
[Document to be Amended]Specification
[Item(s) to be Amended]Whole sentence
[Method of Amendment]Change
[The contents of amendment]
[Document Name]Specification
[Title of the Invention]A module type, high energy, extensive wavelength variable nature, ultra high-speed, a fiber light source
[Claim(s)]
[Claim 1]Laser system comprising:
Spectral band width of 0.3 nm or more.
A source of seed light which generates a pulse of the wavelength range with about 50 fs(es) and pulse width during 1 ns of 1-1.15 micrometers.
A fiber amplifier for a pulse of a wide bandwidth which outputs a pulse which inputted, amplified and amplified this pulse.
A pump laser for supplying laser energy to this fiber amplifier.

[Claim 2]Laser system characterized by comprising the following about claim 1.
Said source of seed light is fiber laser.
A nonlinear crystal which carries out frequency multiplying of the output of the Raman shifter which inputs an output of this fiber laser, and this Raman shifter.

[Claim 3]Said Raman shifter is a fiber of a silica base which carries out upper part conversion in a spectral range longer than 2000 nm, and further a radiation wavelength of said fiber laser said nonlinear crystal, Then, laser system about claim 2 which carries out lower part conversion of this wavelength by which upper part conversion was carried out in a 1000-1500-nm spectral range.

[Claim 4]Laser system about claim 2 whose wavelength alignment curve of a nonlinear crystal is below a center wavelength of an output of the Raman shifter.

[Claim 5]Laser system about claim 2 which has an amplification fiber with rare earth amplification ion selected since said Raman shifter generated a pulse of a non-amplification fiber or refractive index distribution, and the wavelength range of about 600-5000 nm.

[Claim 6]A silica Raman shift fiber which said source of seed light inputs an output of Er fiber laser and this Er fiber laser, and is outputted to said fiber amplifier, Laser system about claim 1 in which it has a fluoridation Raman shifter which inputs said amplified pulse, and said fiber amplifier is a Tm fiber amplifier.

[Claim 7]Laser system about claim 6 which has further a nonlinear crystal which inputs an output of a fluoridation Raman shift fiber so that frequency multiplying may be performed.

[Claim 8]Laser system characterized by comprising the following about claim 1.
Said source of seed light is Er fiber laser.
The Raman shifter which inputs a frequency multiplying output of a nonlinear crystal which inputs an output of this Er fiber so that frequency multiplying may be performed, and this nonlinear crystal.

[Claim 9]Laser system about claim 8 which said source of seed light is passive mode locking fiber laser, and is a HORI fiber used in order for said Raman shift fiber to carry out the Raman shift of the frequency multiplying output of a nonlinear crystal to the wavelength range of about 750 to about 1050 nm.

[Claim 10]An amplification fiber with rare earth amplification ion which said source of seed light is passivity type mode locking fiber laser, and is different from a series of non-amplification fibers and different refractive index distribution. Laser system about claim 8 used in order to carry out the Raman shift of the frequency multiplying output of said nonlinear crystal to the wavelength range of about 750 to about 5000 nm.

[Claim 11]Laser system about claim 1 with which said source of seed light has passivity type mode locking fiber laser.

[Claim 12]Laser system about claim 11 in which said passivity type mode locking fiber laser is Yb fiber laser.

[Claim 13]Laser system about claim 11 in which said passivity type mode locking fiber laser is Nd fiber laser.

[Claim 14]Laser system about claim 11 in which said passivity type mode locking fiber laser is in many modes.

[Claim 15]Laser system about claim 14 in which said passivity type mode locking fiber laser is polarization maintenance.

[Claim 16]Laser system about claim 11 in which said passivity type mode locking fiber laser is polarization maintenance in a single mode.

[Claim 17]Laser system characterized by comprising the following about claim 1.
Said source of seed light is fiber laser.
A frequency shift fiber which inputs an output of this fiber laser and outputs an anti-stokes blue

shift output.

[Claim 18]Laser system about claim 17 in which said fiber laser is Er, Er/Yb, or Tm fiber laser.

[Claim 19]Laser system about claim 1 which generates a pulse to which said source of seed light induces generation of a parabolic pulse with said fiber amplifier.

[Claim 20]Laser system about claim 19 which has further a coupler of said source of seed light, and said fiber amplifier which does, combines this source of seed light with this fiber amplifier, and has an optical fiber 1 km or less in length.

[Claim 21]Laser system about claim 1 which has further the optical supply fiber combined with an output of said fiber amplifier.

[Claim 22]Laser system about claim 21 chosen from a group which said optical supply fiber becomes from one number mode fiber connected to a HORI fiber, one number mode fiber and 1, or two single mode fibers.

[Claim 23]Laser system about claim 22 in which said source of seed light generates a pulse shorter than 100ps so that generation of a parabolic pulse may be induced with said fiber amplifier, and said fiber amplifier has a larger profit than 10 further.

[Claim 24]Laser system about claim 23 which has further a pulse dilator which outputs a pulse which extended this pulse dispersively when just right, and this extended it in response to a pulse from said source of seed light to said amplifier.

[Claim 25]Laser system about claim 24 which is the thing that it has a pulse compressor which compresses said amplified pulse in time, and this pulse compressor outputs a bandwidth marginal pulse about, as for distribution of this pulse compressor.

[Claim 26]Laser system characterized by comprising the following about claim 1.
Said source of seed light is Tm or Ho fiber laser.
A nonlinear crystal which inputs an output of this Tm or Ho fiber laser, and performs frequency multiplying.

[Claim 27]Laser system about claim 1 by which either Yb or Nd is added as for said fiber amplifier.

[Claim 28]Laser system about claim 1 which has further a pulse compressor for compressing an amplified pulse about in time to a bandwidth limit.

[Claim 29]Laser system about claim 1 which is the semiconductor laser in which direct modulation of said source of seed light was carried out.

[Claim 30]Laser system comprising:
A source of seed light which generates a pulse of the wavelength range with larger spectral band width, about 50 fs(es), and pulse width during 1 ns than 0.3 nm of 1-1.15 micrometers.
A pulse dilator which outputs a pulse which extended this pulse dispersively when just right, and this extended it in response to this pulse.
A clad pump fiber amplifier which has a bigger profit than 10, and amplifies and outputs it in response to a this extended pulse to a pulse of a wide bandwidth.
A pulse compressor which inputs a pulse [this] amplified and extended and compresses them in time to a bandwidth limit about.

[Claim 31]Laser system about claim 30 in which said pulse dilator has a fiber 1 km or less in length.

[Claim 32]Laser system about claim 30 in which said pulse dilator has a HORI fiber.

[Claim 33]Laser system about claim 30 in which said pulse dilator has one minority mode fiber.

[Claim 34]Laser system about claim 30 in which said pulse dilator has one minority mode fiber joined together with a single mode fiber of 1 or a large number.

[Claim 35]Laser system about claim 30 in which said pulse dilator has a single mode fiber 1 km or less in length.

[Claim 36]Laser system about claim 30 which has a fiber in which said pulse dilator has W-like refractive index profile.

[Claim 37]Laser system about claim 30 which has a fiber in which said pulse dilator has a multi-clad refractive index profile.

[Claim 38]Laser system characterized by comprising the following about claim 30.
One fiber in which said pulse dilator has the 3rd negative distribution.
A linearity chirp fiber diffraction grating with negative secondary distribution.

[Claim 39]Laser system characterized by comprising the following about claim 30.
Said pulse dilator is a linearity chirp fiber diffraction grating.
One or more fiber transmission gratings which have a value which can choose the 3rd high order distribution so that high order distribution may be compensated with a pulse compression means.

[Claim 40]Two or more additional fiber amplifiers connected between said pulse dilator and said pulse compressor, A fiber coupling machine which has an optical fiber 1 km or less in length, and combines said source of seed light with the first one of the additional amplifiers of this plurality, Laser system about claim 30 which has further two or more pulse collection means arranged whether they are before this fiber amplifier, after an additional fiber amplifier of this plurality or middle of one of these amplifiers, and ********.

[Claim 41]An amplifier which operates with a source of seed light which generates a pulse of the wavelength range with larger spectral band width characterized by comprising the following than 0.3 nm, about 50 fs(es), and pulse width during 1 ns of 1-1.15 micrometers, at least one front path, and one back path.
A clad pump fiber amplifier of a pulse sake of a wide bandwidth amplified and outputted in response to this pulse.
An optical modulator arranged between a pump laser for supplying laser energy to this fiber amplifier, one front path of this amplifier, and one back path.

[Claim 42]With two or more additional fiber amplifiers here at least one and two or more additional fiber amplifiers, . Operate with at least one front path and one back path. Laser system about claim 41 which has further a mode filter which penetrates preferentially dominant mode of an amplifier arranged after a path of the beginning of at least one aforementioned fiber amplifier which operates with at least one front path and one back path, and two or more additional fiber amplifiers.

[Claim 43]Laser system about claim 42 which has further one pulse collection machine arranged between at least one front path and one back path.

[Claim 44]A pulse light source which operates with a bigger output wavelength than 2 micrometers, comprising:
A source of seed light which outputs a pulse of short pulse width.
The first fiber Raman shifter which inputs this pulse and generates this output wavelength.

[Claim 45]A pulse light source about claim 44 which has further at least one additional fiber Raman shifter connected to said first fiber Raman shifter, and two or more fiber amplifiers connected by turns between these fiber Raman shifters.

[Claim 46]A pulse light source selected below at Raman-spectrum element-center wavelength of a seed pulse by which was been a pulse light source about claim 45 which has further the multiplying crystal connected to one of the last of said fiber Raman shifter, and the Raman shift of the wavelength alignment curve of this nonlinear crystal was carried out, and it was amplified.

[Claim 47]A lightwave pulse light source comprising:
Passivity type mode locking fiber laser.
Yb amplifier for amplifying an output of this fiber laser.

[Claim 48]A lightwave pulse light source about claim 47 in which said passivity type mode locking fiber laser has Yb fiber laser.

[Claim 49]An optical-communications subsystem comprising:
A pure normal dispersion fiber light amplifier connected to an optical fiber penetration line with a profit of 10dB/km or less, and a comprehensive profit of not less than 10 dB.
A dispersion compensation element arranged on this optical fiber penetration line, and a light filter arranged on this optical fiber penetration line.

[Claim 50]An optical-communications subsystem comprising:
A pure normal dispersion fiber light amplifier connected to an optical fiber penetration line with a profit of 3dB/km or less, and a comprehensive profit of not less than 20 dB.
A dispersion compensation element arranged at an end of an optical fiber penetration line.

[Claim 51]A quantity of self-phase modulation received by a lightwave pulse which is an optical-communications subsystem and penetrates this optical fiber penetration line characterized by comprising the following is an optical-communications subsystem with more normal-dispersion-optical-fiber element also to a twist at a **** dispersive device.
A normal-dispersion-optical-fiber element connected to an optical fiber penetration line.
A **** dispersive device too connected to an optical fiber penetration line.

[Claim 52]An optical-communications subsystem with which said negative dispersive devices were enumerated by claim 51 which has a chirp fiber diffraction grating.

[Claim 53]Quantity of self-phase modulation received by a lightwave pulse which is an optical-communications subsystem and penetrates an optical fiber penetration line characterized by comprising the following. It is an optical-communications subsystem with more HORI fiber also to a twist at a **** dispersive device.
Two or more HORI fibers with pure normal dispersion connected to an optical fiber penetration line.
Two or more **** dispersive devices too connected to an optical fiber penetration line.

[Claim 54]An optical-communications subsystem with which it is an optical-communications subsystem which inputs a pump train of impulses with length for 10 or less ns, also inputs a

lightwave signal, amplifies, and has an optical Raman amplifier fiber to output, and this lightwave signal spreads this Raman amplifier fiber to a counter direction about a pump pulse.

[Claim 55]An optical-communications subsystem about claim 54 aligned by alignment operation in which said optical Raman amplifier is carried out by said pump pulse.

[Claim 56]An optical-communications subsystem characterized by comprising the following about claim 55.
A source of seed light which outputs a lightwave pulse.
A modulator which modulates this lightwave pulse.
The Raman shifter fiber which inputs a modulated this lightwave pulse.
A Raman amplifier which inputs an output of this Raman shifter fiber.

[Claim 57]An optical-communications subsystem about claim 56 including that said alignment operation modulates at least one of power of this seed pulse, wavelength, and the width before said seed pulse is poured into said Raman shifter fiber.

[Claim 58]Laser system about claim 9 which is a HORI fiber which changes on wavelength so that said Raman shift fiber may optimize said Raman shift in a meaning with distribution.

[Claim 59]Laser system with which this seed pulse is generated and this fiber amplifier is formed so that it may be laser system and a pulse made with this fiber amplifier may be parabolic, comprising:
A light source of a seed pulse.
A fiber amplifier which inputs and amplifies this seed pulse.

[Claim 60]Laser system which is laser system and generates a pulse to which the source of seed light induces parabolic pulse form Shigeru with this fiber amplifier, comprising:
A light source of a seed pulse.
A fiber amplifier which inputs this seed pulse, amplifies and outputs an amplified pulse.

[Claim 61]Laser system with which this seed pulse is generated and this fiber amplifier is formed so that it may be laser system and a pulse made with this fiber amplifier may be parabolic, comprising:
A light source of a seed pulse.
A fiber amplifier which outputs a pulse which inputted, amplified and amplified this seed pulse.

[Claim 62]An optical-communications subsystem comprising:
A light source of a lightwave pulse of different wavelength.

A means to correct dynamically a degree of a Raman shift experienced in each of this different **** wavelength.

[Claim 63]Improvement which has at least one Raman shifter in an optical fiber communications system of a type which has a fiber light carrier circuit which conveys a lightwave signal of different wavelength, and at least one fiber laser amplifier which imposes a profit which is different to a signal of this different **** wavelength.

[Claim 64]A source of seed light characterized by comprising the following for laser system.
Fiber laser which generates a pulse output.
A nonlinear crystal which carries out frequency multiplying of the output of the Raman shifter which inputs a pulse output of this fiber laser, and this Raman shifter.

[Claim 65]A source of seed light characterized by comprising the following for which claim 64 was asked.
A heavy current nature optical material in which said nonlinear crystal was chosen from a group which consists of PPLN, PP lithium tantalate, PPMgO:$LiNbO_3$, and PP KTP and which carried out the pole periodically.
A crystal in which a KTP isomorph carried out the pole periodically.

[Claim 66]A source of seed light which is a source of seed light for which claim 65 was asked, and is selected in order that the section of said nonlinear crystal may control the pulse length of a pulse output of this source of seed light.

[Claim 67]A source of seed light which is controlled by an output wavelength of said nonlinear crystal controlling temperature of this nonlinear crystal and for which claim 65 was asked.

[Claim 68]A distribution system for fiber laser systems characterized by comprising the following which operates in parabolic pulse organization.
A supply fiber.
W-fiber for compensating the 3rd distribution of a diffraction grating type pulse compressor and this pulse compressor.

[Claim 69]Dispersion compensation arrangement for fiber laser amplification systems characterized by comprising the following which operates in parabolic pulse organization.
A pulse dilator which is arranged in front of an amplifier stage of this system, and contains at least one negative 3rd distribution generator child.
A pulse compressor arranged after this amplifier stage in order to have the 3rd positive distribution that cancels distribution introduced by this dilator and to compensate secondary

distribution.

[Claim 70]Dispersion compensation arrangement for fiber laser amplification systems characterized by comprising the following which operates in parabolic pulse organization.
A pulse dilator containing at least one Bragg fiber diffraction grating and a fiber transmission grating for being arranged in front of an amplifier stage of this system, and generating at least one positive secondary distribution generator child and the 3rd distribution [4th].
A pulse compressor arranged after this amplifier stage in order to have the 3rd positive distribution that cancels distribution introduced by this dilator and to compensate secondary distribution.

[Claim 71]A wavelength variable Raman amplifier comprising:
A light source of a femtosecond organization seed pulse.
A Raman shift fiber which carries out a wavelength shift in response to this seed pulse in order to form a pump pulse.
A Raman amplifier fiber into which this pump pulse and two or more signal wave long pulses spread to a counter direction were poured.
A means to modulate at least one of power of this seed pulse, wavelength, and the width in order to carry out wavelength alignment of this pump pulse and to align a center wavelength of Raman gain of this Raman amplifier.

[Claim 72]An amplifier by which wavelength alignment is carried out with a time period below signal pulse crossing time of this Raman amplifier so that it may be the amplifier for which claim 71 was asked and said pump pulse may double said signal pulse with an effective correction Raman gain spectrum.

[Claim 73]Wavelength variable laser system comprising:
Fiber laser which generates a pulse output with pulse width for 1 or less nanosecond.
distribution -- a little -- or -- a HORI fiber which changes on wavelength so that wavelength alignment may be optimized.

[Claim 74]Are wavelength variable laser system characterized by comprising the following, are in wavelength tuning range, and this HORI fiber, Wavelength variable laser system in which negative secondary distribution is shown, it has secondary distribution zero to an input pulse light source on wavelength of less than 300 nm, and an absolute value equal to an absolute value of the 3rd material dispersion of silica or the 3rd distribution not more than it is shown.
Fiber laser which generates a pulse output.
distribution -- a little -- or -- a HORI fiber which changes on wavelength so that wavelength alignment may be optimized.

[Detailed Description of the Invention]
[0001]
[Background of the Invention]
1. The wavelength selection of the invention of ****** of an invention is possible, it is compact, it is a module type and this super-short laser pulse light source is a fundamental component [in / about an efficient high-power super-short laser pulse light source / industrial use of ultra high-speed laser technique].
[0002]
2. It is recognized as the description fiber laser of a pertinent art having given the effective medium for ultrashort pulse generating for a long time until now. However, such [until now] a system, . Mainly have the option restricted to wavelength variable nature, and the minimum pulse width that can be attained has a limit. The Bragg diffraction lattice which carried out the chirp. It was based on the used chirp pulse amplification (A.). Galvanauskas and M.E. Fermann, 'Optical Pulse Amplification using Chirped Bragg Gratings, 'United States Patent, No.5,499,134. The Bragg diffraction lattice which carried out the chirp has developed into the device which can be obtained very widely, and in a Bragg diffraction lattice a chirp, Linearity or in order to compensate distribution of the arbitrary order within a chirp pulse amplification system, Nonlinear, Skill is also designed (A. Galvanauskas.). et al. and 'Hybrid Short-Pulse. Amplifiers with Phase-MismatchCompensated Pulse Stretchers and Compressors', U.S.PatentNo.5,847,863, This chirp pulse amplification system is important for generating of pulse ** made shortest for a bandwidth restriction pulse, i.e., the pulse bandwidth of the given spectrum.
[0003]
In order to maximize the power of an optical fiber, and the limit of energy, using chirp pulse amplification, Although it is clearly desirable, simultaneously, the demand (the Bragg diffraction lattice needs to operate by reflection rather from a penetration, in order to give the possible highest distribution) of system integration is not practical, and carries out use of such a standard chirp pulse amplification system. As a substitute of chirp pulse amplification, The high-power pulse amplification in the multimode fiber amplifier was proposed ('Single-mode Amplifiers and Compressors Based M. E. Fermann and D. Harter). on Multi-mode Optical Fibers', UnitedStates Patent, No.5,818,630. What [soliton Raman compression with a fiber amplifier is used for as a substitute of chirp pulse amplification], Or generally, The pulse compression in the inside of a nonlinear fiber amplifier. Using it was proposed (M. 'Apparatus and Method for the GenerationofHigh-power). [E.Fermann, A.Galvanauskas and D.Harter,] Femtosecond Pulses from a Fiber Amplifier', United States Patent, No.5,880,877.
[0004]
Clearly, use of a multimode fiber is combined with chirp pulse amplification and soliton Raman compression in order to improve the performance of such a system further. However, the pulse form-like controlling method for optimizing the whole system performance further till today was not described at all.Similarly, using a self--phase modulation for the dilator portion of such a chirp pulse amplification system was not proposed.
[0005]

What a fiber dispersion delay line is used for jointly with a bulk optical compressor as a compromise of miniaturization of a system, and high-energy-izing, It is advantageous and at least, Partial integration of a high-energy fiber laser system. . Bring. (M. E.FermannA.Galvanauskas.) and D.Harter: 'All fiber souce of 100 nJ sub-picosecond pulse', Appl.Phys.Lett., vol.64-1994, pp.1315-1317. However, in order to repress a pulse to near the bandwidth limit till today, the effective method of controlling higher order 3rd distribution [4th] in the combination of a dilator and a compressor was not developed at all.

[0006]

By using the single mode erbium amplifier of a high-profit normal dispersion (soliton is not supported) silica base as a substitute of chirp pulse amplification combining a bulk prism compressor, It was also proposed before that effective pulse compression is obtained ('Pulse Compression by Nonlinear Pulse Evolution with KTamura and M.Nakazawa). Reduced Optical Wave Breaking in Erbium-Doped Fiber Amplifiers, 'Opt.Lett., Vol.21, p.68 (1996). However, the thing for which this art is used jointly with the erbium amplifier of a silica base, Because it is a problem, it is because the demand for normal dispersion restricts fiber core size to about 5 microns, or negative material dispersion governs positive waveguide dispersion and the whole is made into negative fiber dispersion. Similarly, the multimode fiber of a silica base had negative distribution on erbium amplifier wavelength, and has barred using them for effective pulse compression. Thus, the core size to which the normal dispersion erbium amplifier was limited decreases greatly the pulse energy which can be attained.

[0007]

The method of performing an additional spectrum expansion and pulse amplification after one erbium amplifier was not shown by Tamura and others. The method of making the performance of a prism pulse compressor similarly optimize, in order to compensate distribution of an erbium amplifier was not taught by Tamura and others.

[0008]

Using a non-amplifying optical fiber jointly with a bulk diffraction grating compressor as another substitute of chirp pulse amplification was proposed (D. Grischkowsky et al.and J.Kafka et al., U.S.Patent No.4,750,809). However, since there is no profit in such a system, high pulse energy must be combined with a nonlinear optical element in order to obtain high-output power, and the peak power characteristic of a system is reduced. It did not argue about the method of compensating higher order distribution with such optical arrangement, but it has restricted the implementability of this approach greatly. The spectrum breadth with a linearity chirp is obtained without controlling the shape of a pulse form in the input to such a system only with the input control power limited dramatically. Kafka and others did not argue about control of input pulse shape. Similarly, in order to acquire the shortest possible pulse jointly with a bulk diffraction grating compressor, the secondary distributed control [3rd] in such a nonlinear optical element were needed, but Kafka and others did not argue about this, either.

[0009]

The chromatism compensation in the light wave signal (low power) which uses chromatism into another (distributed-compensation) waveguide device, In order to optimize the performance of a telecommunication system. It was introduced (C. D.Poole, 'Apparatusof compensating chromatic dispersion in optical fibers, 'US Patent No.5,185,827).However, in the case of a high-power

pulse light source, the self--phase modulation introduced by the distributed-compensation waveguide device bars those effective use. In order that the system about which Poole argued may absorb higher mode selectively in a distributed-compensation waveguide device, in order [or] to amplify dominant mode selectively in a distributed-compensation waveguide device -- a mode converter -- and -- or jointly with a rare earth added fiber, it only operates. The method of compensating distribution of the high-power lightwave pulse under existence of a self--phase modulation was not taught at all, and the method of carrying out a distributed-compensation waveguide without a mode converter was not proposed at all.

[0010]

Instead of using a mode converter and higher mode, [******] The refractive index profile of W-style. The fiber which it has is known (B. J.Ainslie.). and C.R.Day and 'A review. of single-mode fibers with modified dispersion characteristics';J.Lightwave Techn., vol.LT-4, No.8, pp.967-979-1988. However, it did not argue about the use of such a fiber design to a high-power fiber chirp pulse amplification system.

[0011]

In order to make efficiency of an ultra high-speed fiber amplifier into the maximum, Use of Yb fiber amplifier was proposed (D. "Broad-bandwidth pulse amplification to the10microj level). [T.Walton, J.Nees and G.Mourou,] in an ytterbium-doped germanosilicate fiber, "Opt.Lett., vol.21, no.14, and pp.1061 (1996) -- however, Although the research by Walton and others adopted argon laser-pumps Ti:sapphire laser as excitation of Yb addition fiber, it not only adopts mode locking Ti:sapphire laser as a light source of a signal pulse, but, Efficiency is [this] bad and clearly incompatible with a compact apparatus dramatically. Although it was not proposed at all, i.e., the 100fs pulse from Ti:sapphire laser was combined with Yb amplifier through a single mode fiber distribution delay line 1.6 km in length, the method of controlling the phase of a lightwave pulse by an amplification process. This delay line starts a big phase distortion by high order distribution, and restricts greatly applying a system to ultra high-speed application. In order to induce a quality high-power parabolic pulse in Yb amplifier, the seed pulse of the range of 200-400fs is more preferred to Yb amplifier of the length which is several meters than to it. Use of the single mode Yb addition fiber amplifier by Walton and others restricts the energy of Yb amplifier, and the limit of power still more greatly. Although use of the multi-mode Yb addition fiber was proposed by U.S. application No.09/317,221 by which the contents were incorporated here as a reference, the small ultrashort pulse light source which is compatible with Yb amplifier remained, while it had been unclear.

[0012]

The Hiroyoshi strange pulse Yb-fiber laser which incorporated the active light modulation mechanism, . Were described recently.(J. Porta.) et al. and 'Environmentally. stable picosecond ytterbium fiber laser with abroad tuning range', Opt.Lett., vol.23, pp.615-617 (1998). Although this fiber laser has provided the tuning range in the profit bandwidth of Yb about, applying that laser to ultra high-speed optics is restricted by the comparatively long pulse generated by that laser. The bandwidth of the pulse which the active mode locked laser generally generated the pulse longer than a passive mode locked laser, and was generated in the case of this actual condition has the minimum pulse width of 5ps, and is [whether it is small and] 0.25 nm.

[0013]

The extensive wavelength variable fiber laser light source which used the Raman shift jointly with the frequency conversion in the inside of a nonlinear crystal was described recently. (M. US) [E.Fermann et al.,] Patent No.5,880,877. and N.Nishizawa and. T. Goto and "Simultaneous. Generation of Wavelength. Tunable Two-Colored Femtosecond Soliton Pulses Using Optical Fibers, "Photonics Techn.Lett., vol.11, no.4, pp421-423 reference. The eternal Raman shifter is proposed spatially fundamentally and, as a result, the wavelength variable range is restricted to 300 to 400 nm (refer to Nishizawa et al.). No methods of making the minimum the noise of such an advanced nonlinear system based on the Raman shift in a nonlinear optical crystal and the application of nonlinear frequency conversion which were continued are known. The system described by Nishizawa and others was based on the comparatively complicated low power polarization control erbium fiber oscillator amplified with the additional polarization control erbium fiber amplifier for seeding the Raman shifter. No methods of making possible the Raman shift of the frequency multiplying output from Er fiber laser are described.

[0014]

The Raman shifter which is a pulse from a high-power fiber oscillator, or was directly seeded by the pulse by which frequency conversion was carried out from the high-power fiber oscillator is clearly preferred. Such a fiber oscillator, These days multimode optical fiber. It was used and described (M. 'Technique for mode-locking of multi-mode fibers and the construction of compact). [E.Fermann,] high-power fiber laser pulse sources', U.S.serial number09/199,728. However, the method of changing the frequency of an oscillator which used the Raman shift after that is not proved till today.

[0015]

[Summary of the Invention]

Therefore, the purpose of this invention is to be easy to modularize and to provide small size, an extensive wavelength variable, a high peak, high average power, and low noise ultra high-speed fiber amplification laser system.

[0016]

1) The source of short pulse seed light, 2 extensive bandwidth fiber amplifier, 3 distribution pulse expansion element, 4) a distributed pulse compression element, 5 nonlinear frequency conversion element, the optic for 6 fiber distribution, and ** -- it is another purpose of an invention to ensure modularization of a system by using various easily exchangeable optical systems [like]. The proposed arbitrary modules may comprise a part of exchangeable optical system.

[0017]

It is another purpose of an invention that the distributed delay line integrated highly and the effective fiber amplifier by which the pump was carried out directly or indirectly by the diode laser ensure the miniaturization of a system by using it. The high-peak-power characteristic of a fiber amplifier is using the optimized shape of a pulse form of parabolic or others, and is expanded greatly. Jointly with self-phase modulation, a parabolic pulse enables generating of a large bandwidth and a high-peak-power pulse, and distributed pulse extension controlled well. The high gain which operates on the wavelength which is positive has the single material dispersion of a fiber, or a high-power parabolic pulse is generated with a multimode fiber amplifier.

[0018]
or [that a parabolic pulse is distributed along with considerable fiber length also under existence of self-phase modulation or general Kerr effect type optical nonlinearity] -- or it is spread and only a pulse chirp [enough linearity] is caused.At the end of such fiber distribution or a fiber propagation line, a pulse is about compressed to a bandwidth limit.
[0019]
The high energy characteristic of a fiber amplifier is greatly expanded by using chirp pulse amplification jointly with a parabolic pulse or other shape of optimal pulse form, and the shape of the pulse form can permit much [without degradation of pulse quality] self-phase modulation. The chirp pulse amplification system integrated more by the altitude, It is made from using the nonlinear crystal (the pole was carried out) which connects a bulk optical pulse compressor (or low nonlinearity Bragg diffraction lattice) or pulse compression to frequency conversion and by which polarization was carried out periodically, without spoiling the high energy characteristic of an optical fiber.
[0020]
Distribution with a fiber pulse dilator and a bulk optical compressor is incorporating a fiber pulse dilator with the secondary distribution [3rd / 4th] that can be adjusted, and suits to the 4th phase. The high order distribution which can be adjusted is obtained by using a standard stair-like refractive-index-distribution (step index) high numerical aperture fiber jointly with a linearity chirp fiber diffraction grating, using only a high numerical aperture single mode fiber with the optimized refractive index distribution. Or high order distribution is using a linearity chirp fiber diffraction grating jointly with a transmission type fiber diffraction grating, using a nonlinear chirp fiber diffraction grating, using the dispersion property of the higher mode in the number mode fiber of a high numerical aperture, and is controlled. The 4th distribution that can be adjusted is using the fiber which controls the chirp of a fiber Bragg diffraction grating and a transmission type fiber diffraction grating, and has the secondary distribution [3rd / 4th] of a different rate, and is obtained. Similarly, high order distribution is obtained by using the nonlinear crystal which carried out the pole periodically.
[0021]
A fiber amplifier is seeded with the short-pulse-laser light source which carried out the form of the short pulse fiber light source preferably. In the case of Yb fiber amplifier, the frequency multiplying short pulse Er fiber laser light source which carried out the Raman shift is mounted as a source of extensive wavelength variable seed light. In order to make the noise of the frequency conversion from 1.5 micrometers to 1.0 micrometer into the minimum, the self--restriction Raman shift of Er fiber laser pulse light source is used. Or the noise of a nonlinear frequency conversion process is minimized by carrying out self--limit frequency multiplying. The center wavelength of the alignment curve of a multiplying crystal is shorter than the center wavelength of the Raman shift pulse.
[0022]
The process of a Raman shift and frequency multiplying can also be made reverse. There, frequency multiplying of the Er fiber laser is carried out first, it is the optimized fiber which gives soliton maintenance distribution to the wavelength of not less than around 800 nm after that, and a Raman shift is carried out, and it builds the source of seed light of a 1-micrometer

wavelength area.
[0023]
Mode locking Yb fiber laser is used as a substitute of the source of low-complicated seed light for Yb amplifiers. Fiber laser is designed so that the pulse which carried out the chirp strongly may be made, and in order that a light filter may select the seed pulse close to the bandwidth limit for Yb amplifiers, it is combined.
[0024]
Since a parabolic pulse is transmitted along with sufficient fiber length, the pulse is used also for a fiber optics communications system. In this system, the parabolic pulse generated with the outside pulse light source is transmitted. Or a parabolic pulse is generated also a transmission process. In the latter case, a harmful operation of the optical nonlinearity in transmission systems is generally minimized by mounting a long distribution pattern and normal dispersion light amplifier. Such an amplifier has a profit of a length of at least 10 km, and 10dB/km or less. All the profits per amplifier should exceed 10 dB, in order to utilize the start of the parabolic pulse forming for minimization of a harmful operation of optical nonlinearity. Chirp compensation of a transmission line is using a chirp fiber Bragg diffraction grating also for the end of the transmission line as meeting a fiber transmission line, and is usually carried out. An optical bandwidth filter is further mounted for bandwidth control of the transmitted pulse.
[0025]
The wavelength variable pulse light source based on the Raman shift of the short pulse in an optical fiber is useful at many application, for example, a spectroscopic analysis. However, a very attractive device is made from applying a Raman shift to manufacture of the wavelength variable fiber Raman amplifier for telecommunication systems. In this wavelength variable system, the pump pulse which carried out the Raman shift gives Raman gain for the variable wavelength range, and is shifted to red about a pump pulse. The shape of the Raman gain spectrum is modulating the pump pulse which carried out the Raman shift, and is controlled.
[0026]
[Detailed explanation of the submitted example]
The system chart where the invention was generalized is shown in drawing 1. The pulse generated in the source 1 (seed module; SM) of laser seed light is combined with the pulse extension module 2 (PSM), and, as for a pulse, time is extended dispersively there. The extended pulse is combined with the dominant mode of the Yb fiber amplifier 3 (an amplifier module, AM1) by which the clad pump was carried out, and a pulse is amplified at least 10 times there. Finally, it is combined with the pulse compressor module 4 (PCM), and a pulse is mostly compressed in time to near the bandwidth limit there.
[0027]
the example shown in drawing 1 is a module type -- **, four subsystem;SM1, PSM2, AM13, PCM4, ** and others As indicated in the another example, of course, a subsystem is used for different shape, even when it is individual.
[0028]
Hereafter, an argument relates to a SM-PSM-AM1-PCM system. SM1 has a femtosecond pulse light source (source 5 of seed light) preferably. PSM has the one fiber 6 preferably and combination between SM and PSM is preferably performed by weld. The output of PSM is

preferably poured into the dominant mode of the Yb amplifier 7 inside the AM1 module 3. combination -- the bulk optical imaging system between weld, a fiber coupling machine, or PSM2 and the fiber amplifier 7 -- it is carried out by coming out. All the fibers are preferred and a polarization maintenance type is chosen. PCM4 has preferably a distributed delay line formed by one or two bulk optical diffraction gratings for the reason for a miniaturization. Or many bulk optical prisms and Bragg diffraction lattices are used for PCM4. Combination to PCM4 is performed by the bulk optical lens system as described by drawing 1 with the single lens 8. In the case of PCM containing a fiber Bragg diffraction grating, a fiber pigtail is used for the combination to PCM.

[0029]

As an example of the source of femtosecond laser seed light, Raman-shift-frequency multiplying Er fiber laser is shown in SM1b of drawing 2. The femtosecond laser 9 is a commercial high energy soliton light source (IMRA America, Inc., Femtolite B-60TM) which supplies a 200fs pulse on the wavelength of 1.57 micrometers and in which it supplies the pulse energy of 1nJ with the repeating cycle of 50 MHz.

[0030]

For the optimal Raman shift to a 1.5 to 2.1-micrometer wavelength area, reducing core ** (it taper-ized) is performed to the longitudinal direction of the polarization maintenance Raman shift fiber 10. Reduction of core ** is needed in order to maintain the secondary distribution by the Raman shifter to near the zero (however, negative) in the full wave length range up to 1.5 to 2.1 micrometers. By keeping it small, the absolute value of secondary distribution is minimized by the pulse width within the Raman shifter, and it this. Maximization of the Raman frequency shift is brought about (J. P.Gordon, "Theory ofthe Soliton Self-frequency Shift, "Opt.Lett., 11,662 (1986)). Without taper-izing, generally the Raman frequency shift is restricted to around 2.00 micrometers, and these 2.00 micrometers are not in agreement with the profit bandwidth of Yb fiber amplifier after frequency multiplying.

[0031]

In this special example, the two-step Raman shifter 10 which consists of a silica 'Raman' fiber (it is a single mode at 1.56 micrometers) of length (30m and 3m) which has core ** (6 micrometers and 4 micrometers), respectively is mounted. When the beginning of the infrared-absorption end of silica is 2.0 micrometers, it is advantageous to increase the taper-ized rate to the terminal direction of the Raman shifter 10. In this example, not less than 25% of the conversion efficiency from 1.57 micrometers to 2.10 micrometers is acquired. Better conversion efficiency is acquired by mounting a single taper-ized fiber with core ** which changes smoothly more using many fibers with core ** which changes smoothly.

[0032]

Frequency conversion to the 1.05-micrometer field of the pulse which carried out the Raman shift is performed by the LiNbO3 (PPLN) crystal 11 of one have the polling cycles selected suitably which carried out the pole periodically.(Although it indicates that a desirable material for frequency conversion is PPLN over all these specifications) It should be understood that the crystal in which a heavy current nature optical material like PP lithium tantalate which carried out the pole periodically [others], PP MgO:$LiNbO_3$, and PP KTP, or the KTP isomorph carried out the pole periodically is also used advantageously. The combination with PPLN crystal 11, It

is carried out to drawing 2 using the lens system indicated to be the lens 12. The output of PPLN crystal 11 is combined with the output fiber 13 with the lens 12. In the case of 2.1-micrometer frequency multiplying, the conversion efficiency of 16% is acquired, and the pulse energy to 40pJ is brought about as a result in a 1-micrometer wavelength area. The spectral band width of the pulse by which frequency conversion was carried out is selected by suitable selection of the length of PPLN crystal 11, for example, a PPLM crystal 13 mm in length generates the bandwidth of 2 nm in the 1.05-micrometer field corresponding to the pulse width of about 800 fs(es). The generated pulse width is proportional to the length of a PPLN crystal about. That is, the pulse with the pulse width of 400fs by which frequency conversion was carried out needs PPLN 6.5 mm in length. The pulse width of 100fs to which the pulse which continued and carried out the Raman shift until the pulse width to which frequency conversion of this pulse width reduction was carried out reached about 100 fs(es) was restricted restricts reduction of the further pulse width.

[0033]

When the pulse width by which frequency conversion was carried out is longer than the pulse width of the pulse which carried out the Raman shift enough, the wide bandwidth of the Raman pulse is utilized in order to enable wavelength alignment of a pulse by which frequency conversion was carried out. That is, effective frequency conversion is obtained on frequency for the pulse ranges from 2 (omega1-deltaomega) to 2 (omega1+deltaomega). Here, 2deltaomega is the spectral band width in the half of the maximum of the spectrum of the pulse which carried out the Raman shift. Continious wave length alignment here is simply performed by adjusting the temperature of the frequency conversion crystal 11.

[0034]

The Raman shifter and the noise by which combination ** of the PPLN crystal was amplified are minimized as follows.The self-restriction Raman shift of Er fiber laser pulse light source is used by extending a Raman shift to the larger one in the optical fiber of a silica base than 2 micrometers. In the case of not less than 2-micrometer wavelength, the infrared-absorption end of silica begins to decrease a pulse greatly, and restriction of a Raman shift and reduction of amplification change are brought about. That is, the pulse energy in 1.5 micrometers which increased is useful to shift to bigger absorption than a bigger Raman shift and a 2-micrometer wavelength area, and this increase follows and stabilizes the pulse amplitude in this field which carried out the Raman shift.

[0035]

Or it is shorter than the center wavelength of the pulse which the noise of the nonlinear frequency conversion process was minimized by performing self-limit frequency multiplying, and carried out the Raman shift of the center wavelength of the alignment curve of a multiplying crystal in that case. Again, the pulse amplitude which the pulse energy in a 1.5-micrometer field which increased caused the frequency conversion efficiency which moved to the bigger Raman shift and decreased, therefore carried out frequency multiplying is stabilized. therefore, input control power is big -- even if it changes, the fixed power by which frequency conversion was carried out is obtained.

[0036]

This is shown in drawing 3, and is and the average power in a 1-micrometer wavelength area by

which frequency conversion was carried out is shown as a function of the average input control power in 1.56 micrometers here. Self--limit frequency multiplying ensures that the frequency shift in a 1-micrometer wavelength area is not dependent on the average input control power in the wavelength area which is 1.56 micrometers, as shown also in drawing 3.

[0037]

There are some things which can be chosen in PSM2. In order to acquire the pulse near a bandwidth limit from a system when one fiber (extended fiber) is used as PSM as shown in drawing 1, a suitable distributed delay line is used for PCM4. However, as the distributed delay line of PCM4 is shown in drawing 4, when it comprises the diffraction grating 14 of bulk, a problem may arise.the secondary ratio [3rd] -- the secondary ratio [3rd] in the typical stair-like refractive-index-distribution optical fiber in which the |3/2| next distribution operates in a 1-micrometer wavelength area -- compared with |3/2| next distribution, it is 1 to 30 times larger in a diffraction grating type distribution delay line. In the case of a standard stair-like refractive-index-distribution fiber with the low numerical aperture which operates in a 1-micrometer wavelength area, the numerals of the 3rd distribution with a fiber are the same as that in a diffraction grating type distribution delay line. Thus, jointly with a diffraction grating type dilator, a fiber dilator does not become a reserve means of the 3rd high order distribution by system compensation-sake.

[0038]

In order to perform pulse extension of 10 or more times, control of the 3rd high order distribution becomes important for the optimal pulse compression of PCM4. The fiber in which the extended fiber 6 of PSM2 has W-like multi-clad refractive index distribution in order to overthrow this problem, that is, 'W-fiber' (B. J.Ainslie.) et al or a HORI fiber (T. M.Monroe.) It is replaced with etal., 'Holey Optical Fibers'An Efficient Modal Model, J.Lightw.Techn., vol.17, no.6, and pp.1093-1102. Both W-fiber and a HORI fiber permit the secondary adjustment possible value [3rd] of high order distribution. With possible small core size, the value of the 3rd bigger distribution than the value in a standard single mode fiber is obtained with W and a HORI fiber. Mounting is similar to being shown in drawing 1.

It is not displayed independently.

I hear that the PSM operates with a transmission type purely, and the predominance of such a system has it. That is, PSM avoids use of the distributed Bragg diffraction lattice which operates with a reflection type, and is connected and removed by the system for a different system configuration.

[0039]

PSM2 [another] with the secondary adjustment possible value [3rd] of the 4th distribution is shown in drawing 5. As for PSM20a, the usual stair-like refractive-index-distribution optical fiber is based on positive, zero, or the principle that it undertakes, and it shifts and that 3rd distribution can be made. The value of the 3rd highest distribution is made from the thing in a fiber for which the higher mode of the beginning of a fiber and LP gas_{11} mode near the cut-off are used. By drawing 5, the 4th distribution [3rd] of PSM20a are using the three sections 15, 16, and 17 of a pulse extension fiber, and is adjusted. The first extended fiber 15 is one fiber with the 3rd suitable distribution [4th] of zero. It is connected to the 2nd extended fiber 16, and as well as all the chirp pulse amplification systems, the first extended fiber 15 is selected in order to

compensate the 3rd distribution of a diffraction grating compressor. In order to secure the predominance of the 3rd distribution in LP gas_{11} mode, centering on as mutual a fiber as the 2nd extended fiber 16, the first extended fiber 15 has offset, and is connected, and the main excitation in LP gas_{11} mode in the 2nd extended fiber 16 is brought about. In order to maximize the value of the 3rd distribution with the 2nd extended fiber 16, a fiber with high numerical aperture NA>0.20 is desirable. In order to return the LP gas_{11} mode to the dominant mode of the 3rd extended fiber 17, similar connection technology is used by the trailer of the 2nd extended fiber 16. The 4th distribution of all the amplifiers and a compressor is minimized by suitable selection of a fiber. The 3rd extended fiber 17 has the distribution which can be disregarded, and is made short.

[0040]

By the loss beyond 50% or it which is received by performing the power propagation to LP gas_{01} mode from LP gas_{11} mode without use of an optical mode converter and which is not avoided, the propagation loss of all the fiber dilator assemblies is at least 25%. The energy of the emainder in LP gas_{01} mode of the 2nd extended fiber is reflected by the reflection type fiber grating 18 which can be chosen, as shown in drawing 5. It permits eliminating one mode selectively to another side by the pulse which changes while a diffraction grating resonance wavelength is ten to 40 nm between the two modes, and has the spectral band width [it is ten to 40 nm] of a between according to a difference with a big effective refractive index between dominant mode and the following higher mode.

[0041]

The energy loss of a fiber dilator assembly is aligning the 3rd extended fiber 17 with Yb amplifier, and is made small. This mounting is not shown independently.

[0042]

When the 4th distribution is not large, the first extended fiber 15 is removed. The 4th distribution will also be compensated with using the first extended fiber with the 3rd distribution that is not zero if the 4th distribution even differs from the 3rd order between the beginning and the 2nd extended fiber.

[0043]

Yb addition level is 2.5-mol %, and Yb addition fiber inside AM13 is 5 m in length. In order to use Yb addition fiber in both a single mode and the many modes and to optimize the spatial quality of an output beam, in the case of a multimode fiber, dominant mode is excited, but the core diameter of a fiber changes between 1-50micrometers. Yb addition fiber of different length is used depending on the value of the profit needed. In order to generate the possible highest pulse energy, Yb fiber 1 m in length is mounted.

[0044]

Pulse compression is performed by PCM4. PCM4 includes the usual bulk optic (it is (like the bulk diffraction grating pair shown in drawing 4)), a single diffraction grating compressor or many dispersing prisms, GURIZUMU, and other distributed delay lines.

[0045]

Or a fiber, a bulk black diffraction grating, or the crystal that carried out the chirp and that carried out the pole periodically is used. The crystal which carried out the chirp and which carried out the pole periodically, Pulse compression and the function of frequency multiplying.

Connecting (A. et) [Galvanaskas,] al. and 'Use of chirped. quasi-phase matched materials in chirped pulse amplification systems'U.S.Application No.08/822, 967, and the contents of those, It operates with the transmission type materialized with the reference here, and an original compact system is provided.

[0046]

Change and correction of the others to this invention are clear to what became skillful in the art from an old indication and instruction.

[0047]

Especially SM1 is used as an independence unit for making the femtosecond pulse limited near the bandwidth of 1.52 - 2.2 micrometers of frequency domains, and it is used to make the pulse of 760 nm - 1.1 micrometers of frequency domains after the frequency conversion in a nonlinear crystal. A frequency domain is further expanded by using other optical fibers with an infrared-absorption end longer than a fluoridation Raman shift fiber or silica. The wavelength of about 3 - 5 or more micrometers is attained using this art. With frequency multiplying, 760 nm to 5000 nm and the continuous tuning of until are attained. The pulse power of a 2-micrometer field is using Tm or Ho addition fiber, and is raised further. The Raman soliton pulses which have the pulse energy exceeding 10nJ near the bandwidth limit with such an amplifier are supplied to the single mode fiber of a 2-micrometer wavelength area. A femtosecond pulse with the energy of the number nJ is obtained without use of a distributed pulse compressor in a 1-micrometer field after frequency multiplying. Such a pulse is used as a high energy seed pulse for the multi-mode Yb amplifier of a big core, and a multi-mode Yb amplifier needs seed pulse energy higher than a single mode Yb amplifier, in order to suppress the amplified spontaneous emmision.

[0048]

An example of the super-extensive wavelength variable fiber light source combined with Er fiber laser pulse light source 19 with the silica Raman shifter 20, Tm addition amplifier 21, and the 2nd fluoridation glass base Raman shifter 22 is shown in SM1c of drawing 6. ; the frequency multiplier which can be chosen is not indicated to be -- because of the optimal stability, all the fibers must be polarization maintenance. ; for which the combination of a diode laser pulse light source with Er amplifier is used as another thing replaced with Er fiber laser pulse light source -- separate this and it is not shown.

[0049]

As another substitute of SM, SM1d is shown in drawing 7 and it has the frequency multiplying high-power passivity type mode locking Er or the Er/Yb fiber oscillator 23 jointly with the Raman shift HORI fiber 24. Here the pulse from the oscillator 23 which operates in a 1.55-micrometer wavelength area, The Raman shift of the pulse by which frequency multiplying was first carried out to the frequency multiplier 25 using the lens system 26, and frequency multiplying was carried out after that is carried out with the HORI fiber 24 which gives soliton maintenance distribution to the wavelength of not less than 750 nm, or the wavelength of not less than at least 810 nm. The strange, continuously good light source in which the wavelength area operates among about 750 to 5000 nm is made from selecting the Raman shift fiber of a design which amplifies the pulse which carried out the Raman shift, and is different with a 1-micrometer wavelength range or 1.3, and a 1.5 or 2-micrometer wavelength range. The design of such a light source with many attached amplifiers 27 is also shown in drawing 7.

[0050]

For the optimal Raman self--frequency shift, the Hawly fiber dispersion must be optimized as a function of wavelength. the absolute value of the 3rd distribution of a HORI fiber -- below the absolute value of the 3rd material dispersion of silica -- or it must be equal. This is useful to ensure that the absolute value of secondary distribution remains small in most alignment wavelength ranges. The value of secondary [further] distribution must be negative and the secondary distribution zero must be less than 300 nm from seed input wavelength.

[0051]

As another substitute of the source for Yb amplifiers of seed light, anti-stokes generating with an anti-stokes fiber is used. After anti-stokes generating, in order to make a large wavelength variable light source, the fiber amplifier and the Raman shifter of additional length are used. The frequency multiplication means 25 is omitted and the Raman shifter means 24 is replaced with an anti-stokes generating means here where general composition is similar to what is shown in drawing 7. For example, in order to generate the light of a 1.05-micrometer wavelength range efficiently in the anti-stokes generating means which used the source of Er fiber laser seed light which operates at 1.55 micrometers, the anti-stokes generating means which considered the form with the 3rd distribution of a low value of the optical fiber as the small core is the optimal. The low value of the 3rd distribution is defined as the value of the 3rd small distribution here compared with the value of the 3rd distribution of the standard electronic-communications fiber in 1.55 wavelength areas. The value of secondary distribution of an anti-stokes fiber must be negative.As another source of alternative seed light of Yb amplifier, passive mode locking Yb or Nd fiber laser is used for the inside of SM.Preferably, Yb soliton oscillator which operates by negative distribution is used. ; by which negative resonator distribution is introduced in a resonator by the chirp fiber lattice 29 connected to the output fiber 36 as shown in drawing 8 in order to make Yb soliton oscillator. Or a negative distribution fiber like a HORI fiber (T. Monroe, et al) is used for Yb soliton laser resonator. SM which materializes such arrangement is shown as 1e in drawing 8. Here, the Yb fiber 30 is polarization maintenance, and it is incorporated in order to choose the oscillation to which the light polarizer 31 meets one axis of a fiber (combination is attained by the lens 32). Since it is easy, as shown in drawing 8, the clad pump of the Yb fiber 30 is carried out from the side. However, the passive mode locking Yb fiber laser which incorporates the usual single mode fiber is also used. Such arrangement is not shown independently. In drawing 8, SA28 is used in order to derive short optical pulse formation. The diffraction grating 35 is used for distributed control, and is used as an internal resonator mirror. The pump diode 33 supplies pump light through V groove 34.

[0052]

The arrangement which incorporates a HORI fiber is almost the same as the system shown in drawing 8, and an additional HORI fiber is connected to somewhere in resonators here. When constructing a HORI fiber, a fiber Bragg diffraction grating does not need to have negative distribution, and a Bragg diffraction lattice is similarly replaced by a dielectric mirror.

[0053]

The easiest thing for carrying out is a Yb oscillator which operates by normal dispersion, carrying out a deer.

It does not need a negative distribution fiber Bragg diffraction grating or special resonator

elements like a HORI fiber, in order to control resonator distribution.
With a 'parabolic' Yb amplifier (or the usual Yb amplifier), the very compact source of seed light for a high-power Yb amplifier system is acquired. Such a Yb oscillator with the Yb amplifier 40 is shown in drawing 9, and the Yb amplifier 40 is a 'parabolic' Yb amplifier about which it argues later preferably here. The same number is given to the same element as the inside of drawing 8.

[0054]

Although SM1f in drawing 9 has the side pump Yb amplifier 40 which was described about drawing 8, other pumping arrangement is mounted. Naturally the Yb fiber 44 is polarization maintenance, and it is inserted in order to choose a polarization condition with the single light polarizer 31. The fiber Bragg diffraction grating 37 ensures the oscillation of the pulse which has small reflection band width compared with the profit bandwidth of Yb, and has a small bandwidth compared with the profit bandwidth of Yb. The chirp of the Bragg diffraction lattice 37 is carried out, or a chirp is not carried out. In the case of the Bragg diffraction lattice by which a chirp is not carried out, the chirp of the pulse oscillated within Yb oscillator is just carried out. The pulse generation or the passive mode locking within Yb oscillator can be begun with the supersaturation absorber 28. The optical fiber 39 is additional and restricts further the bandwidth of the pulse sent out to the Yb amplifier 40.

[0055]

In order to optimize parabolic pulse form Shigeru in the Yb amplifier 40 in SM1f, The input pulse width to; and the Yb amplifier 40 in which the input pulse should have a small bandwidth compared with the profit bandwidth of Yb must be small compared with output pulse width, and the profit of the Yb amplifier 40 must be high as much as possible, namely, it must be ten or more. The gain saturation in the Yb amplifier 40 must be small.

[0056]

As an example of a parabolic amplifier, Yb amplifier 5 m in length is used. Parabolic pulse form Shigeru is ensured by using the source of seed light with the pulse width of about 0.2 to 1 ps, and the spectral band width of three to 8 nm. Although parabolic pulse form Shigeru expands the bandwidth of the source of seed light up to about 20 to 30 nm within the Yb amplifier 40, an output pulse can be extended to about two to 3 ps.Since the chirp within a parabolic pulse is linearity highly, the pulse width of 100fs order is obtained after compression. Even if the nonlinear phase shift from the self-phase modulation which can permit a standard ultra high-speed solid amplifier is large, it is only pi (well known for the latest art), but the parabolic pulse fiber amplifier can allow 10*pi and the nonlinear phase shift of the size beyond it. Since it is easy, we call a high gain Yb amplifier a parabolic amplifier. According to a simple contraction scale rule, a parabolic amplifier is increasing amplifier length suitably, and enables generating of a parabolic pulse with 1 nm or the spectral band width not more than it. For example, a parabolic pulse with the spectral band width of about 2 nm is generated by using a parabolic amplifier about 100 m in length.

[0057]

Since the big value of self-abnormal conditions of a parabolic pulse and the big value of the spectrum extension without causing discontinuation of a pulse can be allowed, the peak power ability of a parabolic amplifier is greatly raised compared with a standard amplifier. This is

explained as follows. Time-dependent phase lag phinl (t) received by the self-phase modulation in the optical fiber of length L is proportional to peak power, namely, P (t) is the time-dependent peak power within a lightwave pulse in $phi_{nl}(t)$ P[=gamma] (t) L and here. It is given with the differential coefficient of a phase modulation, namely, frequency modulation is deltaomega=gammaL [**P(t)/**t]. Parabolic pulse profile P (t) In ($-t_0<t<t_0$), frequency modulation is linearity in $=P_0 [1-(t/t_0)^2]$ and here. Then, it is also a pulse profile very much in the parabolic state, and enabling generating of the big peak power only accompanied by linearity frequency modulation and generating of a linearity pulse chirp is shown.

[0058]

The chirp pulse generated with the Yb amplifier 40 is compressed using a diffraction grating compressor as shown in drawing 4. Or the crystal 42 and the lens 41 which carried out the chirp and which carried out the pole periodically are used for pulse compression, as shown in drawing 9. In relation to SM1f shown in drawing 9, the very compact independence light source which gives off the femtosecond pulse in about 530-nm green spectral region is obtained.

[0059]

Since it seeds in Yb amplifier other than the passive mode locking Yb fiber laser 44 shown in drawing 9, another light source is also used. These another light sources can comprise Raman shift Er or Er/Yb fiber laser, the frequency shift Tm or Ho fiber laser, and a diode laser pulse light source. These another mounting thing is not shown independently.

[0060]

The fiber service module (FDM) 45 is added to the base system shown in drawing 1 by drawing 10.In this case, in order that PSM2 may raise; removed, however the peak power ability of an amplification module, PSM2 is contained when required. The Yb amplifier 7 shown in drawing 10 can operate by non-parabolic one and parabolic both.

[0061]

FDM45 consists of the one optical fiber 46 (supply fiber) in the easiest composition. In the case of a parabolic amplifier, direct continuation of the supply fiber 46 is carried out to the Yb amplifier 7, without causing a loss in pulse quality. Rather, also in the case of much self-phase modulation, a linearity chirp is approximately added to the pulse which makes further pulse compression of PCM4 possible by the parabolic pulse profile. PCM4 is integrated by FDM45 with a supply fiber using the small-scale method bulk diffraction grating compressor 14 shown in drawing 4. In this case, the supply fiber linked to a suitable collimate lens is replaced with the input shown in drawing 4. The separate figure of such operation is not shown. However, it will be excluded, if use of PCM4 is subordinate, for example, a chirp output pulse is required from a system. The system indicated to drawing 10 with PCM4 constitutes a derivative chirp pulse amplification system, and while a pulse can extend dispersively about time, of course, as for self-phase modulation, a profit is added here. Adding self-phase modulation to the usual chirp pulse amplification system generally brings about big pulse modification after pulse compression. Use of a parabolic pulse overthrows this restriction.

[0062]

A tip fiber optical fiber communications system is interpreted as a chirp pulse amplification system (for example, D.J.Jones et al., IEICE Trans.Electron., E81-C, 180 (1998) references). Clearly, minimization of the pulse modification by a parabolic pulse is related equally to an

optical fiber communications system.
[0063]
In order to obtain pulse width shorter than 50fs, control of the 3rd high order distribution in an FDM module or the light PSM becomes important. Control of high order distribution of;FDM which already argued about control of the high order distribution by PSM as drawing 1 in relation to 5 is dramatically similar.
It is discussed by the model example of FDM45a shown in drawing 11.
It is used in order that W-fiber of the 3rd big distribution may compensate the 3rd distribution of bulk PCM4, as exactly shown in drawing 1. As exactly shown in drawing 5, high order distribution of all the systems which contain PCM4 which has a bulk diffraction grating by using the fibers 15, 16, and 17 with a different value to high order distribution of FDM is compensated.
[0064]
Another example of PSM is shown in drawing 12 and drawing 13, and they also have the practical value which enables it to use the linearity chirp fiber Bragg diffraction grating which can be obtained to PSM in a commercial scene, and compensate high order distribution of all the chirp pulse amplification systems which have PCM and PSM.As another substitute, in order that a nonlinear chirp fiber Bragg diffraction grating may also compensate distribution of PCM, it is used for PSM. Separate such arrangement and it is not shown.
[0065]
In order to avoid use of W-fiber, or LP gas_{11} mode in PSM, another example of PSM as shown in drawing 12 is shown as PSM2b. It is used for the single mode extension fiber 48 and the circulator 49 with the 3rd negative distribution by the negative linearity chirp Bragg diffraction lattice 47 here, connecting. introduction of a negative linearity chirp Bragg diffraction lattice -- the ratio (the 3rd order/[secondary]) in PSM2b -- when distribution is increased and a bulk diffraction grating compressor is used, compensation of the high value of the 3rd distribution by PCM4 is enabled. PSM2b can also contain W-fiber linked to a linearity chirp fiber Bragg diffraction grating, in order to improve the pliability of PSM further.
[0066]
As another example of PSM for high order dispersion compensation, arrangement is shown in drawing 13 as PSM2c, and it has the positive linearity chirp fiber Bragg diffraction grating 49, the circulator 50, and another fiber transmission grating 51. Here, in order to compensate the linearity in a PCM module, and high order distribution, the positive linearity chirp fiber Bragg diffraction grating 49 makes positive secondary distribution, and other fiber transmission gratings 51 make the secondary additional distribution [3rd / 4th] of a suitable value. One or more fiber transmission gratings or fiber Bragg diffraction gratings are used in order [3rd / 4th] to obtain the suitable value of higher order distribution, if it can do.
[0067]
In order to increase the pulse energy amplified from Yb amplifier to the order of mJ, and more than it, it is mounted as a pulse collection element and the further amplification stage show drawing 14. In this case, the pulse collection machine 52 is amplification stage AM1 of the beginning. 3a and 2nd amplification stage AM2 Amplification module AM1 of between 3b, and PSM2 and the beginning It is inserted between 3a. The arbitrary amplifiers and pulse collection machines of a number are used in order to obtain the possible highest output power, and the last

amplification stage consists of multimode fibers preferably here. In order to obtain a diffraction marginal output, the dominant mode of a multi-mode amplifier is excited selectively, and is guided using the art (M. E.Fermann et al., United States Patent, No.5,818,630) known well. The pulse collection machine 52 is chosen so that it may generally consist of an optical modulator like sound-optics or electric-optical modulation machine. The pulse collection machine 52 reduces only the value which was able to give the repeating cycle of the pulse which comes out from SM1 to from 50 MHz to for example, 5 kHz, and while average power has been small, it enables generating of very high pulse energy. Or since the repeating cycle of a system is fixed to any value, the semiconductor laser which switches directly is also used. The pulse collection machine 52 inserted in the back amplifier stage also stops enhancement of the amplified spontaneous emmision in an amplifier, and makes it possible to centralize output power on a high energy ultrashort pulse. The amplification stage has agreed with PSM and PCM about which it argued before.
Here, it is minimized in order that distribution of all the systems may acquire the shortest possible pulse with the output of a system.

[0068]
Amplifier module AM1 3a is designed like the parabolic amplifier which generates a pulse with a parabolic spectrum. Similarly, it is AM1. The parabolic pulse from 3a is changed into the pulse which has a parabolic pulse spectrum with pulse shaping or the pulse extension fiber 53 as shown also in drawing 14, and the interaction of self-phase modulation and normal dispersion performs this conversion well here. This is because it can evolve into the parabolic pulse in which it will be understood, because a chirp pulse with a parabolic pulse profile has a parabolic spectrum in one fiber. The shape of a parabolic pulse form maximizes the quantity of remarkable self-phase modulation in the next amplification stage, and minimizes in order the quantity of the distributed pulse extension needed by PSM2 and PCM4, and compression. Similarly, the shape of a parabolic pulse form accepts permitting the self-phase modulation of sufficient quantity of PSM2 without big pulse modification.
[0069]
Once a pulse is extended, the harmful influence of the self-phase modulation in the following amplifier will be minimized by using the shape of an even pulse form. As [show / the shape of an even pulse form / in drawing 14 / in order to generate an even pulse spectrum] It is generated by inserting the optical amplitude filter 54 in front of the last amplification module. An even spectrum is because relation direct between the spectrum content after sufficient pulse extension and a time lag is changed into a really even pulse after sufficient pulse extension. Also in the same size as 10*pi, the value of self-phase modulation is permitted to the shape of an even pulse form, without causing big pulse modification.
[0070]
An amplitude filter as shown in drawing 14 is also used when the reconstitution of the pulse spectrum in an amplifier can be disregarded, namely, in order to control high order distribution with the amplifier chain to the pulse which carried out the chirp strongly in existence of self-phase modulation by the outside of the organization in which a parabolic pulse is generated. in this case, $:beta_n^{SPM}=gammaP_0L_{eff}[d^nS(omega)/domega^n]\ omega_{=0}$ which generates the high order distribution

expressed with the following formula of quantity with most self-phase modulation and -- here, P_0 is the peak power of a pulse. S (omega) is the standardized pulse spectrum.
In L_{eff} Ha effective nonlinear length, L is amplifier length in L_{eff}=[exp(gL)-1] / g, and here, and g is the amplifier gain per unit length. Therefore, it is introduced in order that high order distribution of arbitrary quantity may compensate the value of high order distribution by a chirp pulse amplification system with an amplitude filter as shown in drawing 14 by controlling correctly the spectrum of the pulse which carried out the chirp strongly. The phase shift of -10pi truly shown to the 500fs pulse which extended it to about 1 ns is enough to compensate the 3rd distribution of the bulk compressor (as [show / in drawing 4]) which consists of a bulk lattice with 1800 slots/mm. Although an attractive controllable good amplitude filter is a fiber transmission grating, in order that arbitrary amplitude filters may control a pulse spectrum, it is used in front of the amplifier which causes high order distribution, for example.
[0071]
The composition shown in drawing 15 is used as another example over the combination of an amplifier module with a pulse collection machine. Since the pulse of very high energy needs the multimode fiber of the big core for those amplification, it is difficult to control dominant mode by the polarization maintenance fiber amplifier of a single path. In this case, in order to obtain an output beam quality in order to minimize mode coupling, it is preferred to use the unpolarized light maintenance fiber amplifier of central symmetry highly.In order to acquire stable polarization from such an amplifier to deterministic environment, double path composition as shown in drawing 15 is required. Here, an opening is used for; for which the single mode fiber 55 is used as a space mode filter after the path of the beginning of the amplifier 56, or here.The space mode filter 55 cleans the mode after the path of the beginning of the multi-mode amplifier 56, and suppresses the spontaneous emmision by which the higher mode which tends to restrict the profit which can attain a multi-mode amplifier was amplified. The lens 60 is used for the amplifier 56, the space mode filter 55, and the pulse collection machines 52a and 52b in order to carry out joint receipts and payments. It ensures that Faraday rotator 57 polarizes so that front propagation light and back propagation light may cross at right angles, and back propagation light is given off out of a system by the illustrated polarization beam splitter 58. In order to optimize the efficiency of a system, the light source close to a diffraction limit is combined with the dominant mode of the multimode fiber 56 by the input part of a system, and in order that a profit guide may improve further the spatial quality of the beam amplified with the multimode fiber, it is used here. In order to make small the train-of-impulses repeating cycle supplied from SM and to suppress the amplified spontaneous emmision in a multi-mode amplifier, the 1st optical modulator 52a is inserted after the path of the beginning of a multi-mode amplifier. An ideal place is before the reflective mirror 59 so that it may illustrate. As a result, the double path profit of the size of 60 to 70 dB is acquired with such composition, and minimizes the number of the amplification stages demanded from amplifying a seed pulse with pJ energy to mJ energy level. This kind of amplifier agrees with SM_S, PSM_S, and PCM_S about which it argued before thoroughly, and enables generating with the energy of mJ of a femtosecond pulse.Before reducing the repeating cycle of the train of impulses supplied by SM as another substitute of high gain amplifier module construction pours into an amplifier module as shown in drawing 15, it is performed by the 2nd additional modulator 52b. The repeating cycle of the transmission window

of the 1st modulator 52a must be the same as that of the transmission window of the 2nd modulator 52b, or must be lower than it. Such composition is not shown independently. Drawing 15 shares drawing 5 of U.S. Pat. No. 5,400,350 attached here as a reference, and some similarity.

[0072]

As another example of this invention, the optical fiber communications system using parabolic pulse form Shigeru in the long distribution refractive-index type normal dispersion amplifier 61 is shown in drawing 16. The dispersion compensation element 63 is inserted between fiber light amplifiers. In order that the light filter 62 may optimize the pulse forming process in an amplifier, it is mounted further. The optical filter is based on the optical etalon with the limited free spectral range so that it may have the repetition transmission-spectrum characteristic.

The simultaneous penetration of a multi-wavelength channel which is required by a wavelength division multiplex is enabled.

[0073]

The advantageous thing become a key is combining the big profit of a long normal dispersion fiber, in order to linearize the chirp introduced by the optical car nonlinearity of a fiber penetration system. Therefore, generally, the penetration characteristic of an optical fiber communications system is mounting a normal dispersion (non soliton support) amplifier, and improves. Such an amplifier has a length of at least 10 km, and has a profit of 10dB/km or less. In order to use the beginning of the parabolic pulse forming for minimizing the harmful effect of optical nonlinearity, the comprehensive profit per amplifier can exceed 10 dB. The further improvement has a profit of 3dB/km or less, and is increased by using the amplifier which lengthened the overall length so that a comprehensive profit might be not less than 20 dB. The further improvement of the penetration characteristic of a fiber penetration line is obtained by minimizing the quantity of the car nonlinearity of the negative dispersive device of a fiber penetration line. This is attained by using a chirp fiber diffraction grating for a negative dispersive device.

[0074]

It is also advantageous to generate a parabolic pulse in an external light source in addition to parabolic pulse form Shigeru in a penetration line and to pour them into a non soliton support amplifier fiber. In order to use such a system effectively, the low-loss normal dispersion penetration made possible with the HORI fiber is useful. A dispersion compensation element is mounted in a fiber penetration line end as meeting a fiber penetration line. Operation of such a system is similar to what is shown in drawing 16.

It is not shown independently.

The optical fiber communications system with the above similar designs is indicated by provisional application No.60/202,826 attached here as a reference.

[0075]

As another example of this invention in a telecommunication field, a wavelength variable Raman amplifier is built using the Raman shift pulse. Making the Raman gain of signal wave length in which the high-power lightwave signal of the given pump wavelength carried out red shift about pump wavelength is well known for the latest art.In fact, it is the effect of acting on the pump

pulse itself used for construction of the wavelength variable pulse light source about which it argued here.